



Master's Program Informatics

Technische Universität München

Master's Thesis

"Evaluation of Potential for Automotive Engineering Training in Virtual Reality"

Aleksandra Dokic



Master's Program Informatics

Technische Universität München

Master's Thesis

“Evaluation of Potential for Automotive Engineering
Training in Virtual Reality”

Author: Aleksandra Dokic
1st examiner: Univ.-Prof. Dr. Johanna Gudrun Klinker
2nd examiner: Univ.-Prof. Dr. –
Assistant advisor: M.Sc. Sandro Weber
Submission Date: March 15th, 2019

I hereby declare that this thesis is entirely the result of my own work except where otherwise indicated. I have only used the resources given in the list of references.

March 15th, 2019

Aleksandra Dokic

Acknowledgments

If someone helped you or supported you through your studies, this page is a good place to tell them how thankful you are.

"People sometimes ask me if it is a sin in the Church of Emacs to use vi. Using a free version of vi is not a sin; it is a penance. So happy hacking"

-Richard Stallman

Abstract

In the industrial setting, it is necessary to organize introductory and demonstrative courses for the employees which will contain vital information related to the work place, the job assignments and the employee's well being. Unfortunately, these courses often do not relay the intended information due to visualization constraints, inability to reproduce and experiment with the safety critical situations, and high equipment costs for trial and error situations. The advancement and availability of the Virtual Reality (VR) is opening up the possibilities for redesigning industrial courses in order to provide employees with an opportunity for a hands on experience. They could experiment with the realistic setup of the safety critical situations or work with the expensive equipment models without the danger of the injures or causing the material damages.

In this thesis, an example of the VR tutorial was built based on an existing "High voltage Electric Vehicle Security" industrial course. The fourteen employees have been selected to test the application and afterwards participate in the quiz with questions from the VR tutorial content. The user study results show that the employees found the virtual tutorial to be a pleasant and entertaining experience. They specifically enjoyed the realistic feel of the application and felt confident that they could reproduce the same steps in the real world setup. The quiz performance confirms that the participants were able to answer related questions with more then 70% accuracy and generalize the obtained knowledge on the modified tasks.

These positive results obtained from the user study combined with the reasonable development and equipment costs suggest that the VR can bring the industrial education to the new innovative level, help overcome mentioned problems in education and could be a strong interest point for the companies in the future.

Contents

Acknowledgements	vii
Abstract	ix
I. Introduction and Background Theory	1
1. Introduction	3
2. Related work	5
3. Thesis focus and proposed approach	7
3.1. Virtual Reality setup	7
3.2. Technical specifications of the project	8
3.2.1. Head mounted display selection	8
3.2.2. Software	10
3.2.3. Choice of the developing tool	10
II. Thesis implementation and realization	13
4. Intro room in Virtual Reality	15
4.1. Motivation	15
4.1.1. First UI challenges	15
4.1.2. Early design decisions	15
4.1.3. User feedback and redesign	17
4.2. Controllers' buttons functionality	17
4.3. Marking toolkit	18
4.4. Intro room stations	20
4.4.1. Start up station	20
4.4.2. Toolkit selection station	21
4.4.3. Marking intro station	21
4.4.4. Security objects introduction table	22
4.4.5. Garage entering station	23
4.5. Colour coding of the stations	23
	xi

5. Garage room and the objects marking	25
5.1. Static room setup	25
5.2. Garage room instruction stand	26
5.3. Security measures	27
5.3.1. A First Aid kit and an Eyewash liquid	27
5.3.2. A fire extinguisher and a safety rescue hook	28
5.3.3. An alarm plan, an exit sign and a meeting place map	30
5.4. BMW i wallbox	31
5.5. Marking task performance grading	31
6. Working with the vehicle	35
6.1. BMW i3 as a 3D electric car model	36
6.2. Instruction screen for the reminder check list	36
6.3. Switch the electric car off	37
6.4. Disconnect high voltage inside the electric car	38
6.4.1. Enabling the user to locate and identify the emergency disconnect switch	38
6.4.2. Switching the emergency disconnect switch on/off with VR controllers	39
6.4.3. Secure the emergency disconnect switch with the padlock	40
6.5. Disconnect the 12V car battery	41
6.5.1. Locating the 12V car battery	41
6.5.2. Disconnecting the 12V car battery	42
6.5.3. Secure the 12V car battery with a padlock	42
6.6. Determine absence of voltage inside the electric car	43
6.6.1. Model the voltage measuring device	43
6.6.2. Measure the voltage inside the VR course	44
6.6.3. Example virtual objects for the voltage measurement	44
6.6.4. The high voltage points inside the electric car	45
6.7. Mark the electric vehicle as safe to work with	46
6.8. Game logic and user performance grading	47
7. Reusable Scripts	49
7.1. Re-attachable virtual object	49
7.1.1. "Throwable" object from the SteamVR	49
7.1.2. "AttachableThrowable" script	49
7.1.3. "Padlock" script	49
7.1.4. "AttachBack" script	50
7.1.5. Snapping functionality	51
7.2. Sliding virtual objects	51
7.2.1. "Slider" script	51
7.2.2. "Blockable" script	52
7.3. Hidden objects in the VR	53
7.4. Highlight the interacted virtual object	53

7.5. Virtual objects from the exhibition table	54
III. User testing and feedback	57
8. User testing preparation	59
8.1. Testing candidates selection	59
8.1.1. Familiarity with the technology	59
8.1.2. Familiarity with the tutorial content	60
8.1.3. Test groups	60
8.2. Questionnaire for the user study participants	61
8.3. Quiz for the user study participants	63
8.4. Automated time and action tracking and data logging	67
8.5. Testing days	70
9. Result analysis	71
9.1. The test candidates background	71
9.2. Virtual tutorial user experience	73
9.3. Quiz results	74
IV. Results and Conclusion	79
10. Tutorial summary, future work and conclusion	81
10.1. Investment time and costs	81
10.2. Benefits of VR tutorial	81
10.3. Limitations of VR tutorial	82
10.4. Future work	83
10.5. Conclusion	83
Appendix	87
A. Detailed Descriptions	87
Bibliography	89

Part I.

Introduction and Background Theory

1. Introduction

Learning is a never ending process. People have the need to constantly improve already from the early childhood days. In the school, they are faced with simple problems and given time and resources to find the solutions. They are provided with guidance and support. In the end, their performance is judged with certain rewards or punishments. Since they are still in the learning process, the success or failure will have only limited consequences both for them and their surrounding.

However, while the people mature, the learning challenges become only more complex and the pressure to master new set of skills increases. In the industry, the employees have to be trained to perform new tasks, but the negative consequences of failure are not any more negligible. Setting up demonstrative, industrial training is expensive and the trial and error situations could damage valuable equipment. Furthermore, safety critical situations, related to the work positions, can often not be realistically reproduced in order to prepare future employees how to predict, avoid and handle them. Even beyond the limitations of the tutorial content, the time and money invested to build these kind of tutorials can not prevent the knowledge from these courses fading fast from the memory, causing the employees to under perform when facing the same tasks later.

When it comes to obtaining the knowledge for longer periods of time different methods could change the outcome. The information the person has obtained only from reading or hearing it, fades fast. The memory is longer if the task has been demonstrated to the individual and he has seen the task performed. But it is hard to replace the benefits of personal experience which stays the longest in the memory. It is not based only on the visual overview of the task, but additionally on the individual's muscle memory they obtain when their own body experienced the task accomplishment.

The Virtual Reality (VR) technology advancements make it possible to reproduce realistic experiences with high accuracy. The availability of accompanying hardware, head mounted displays, has increased together with its quality and the prices have lowered. It is now affordable for the most companies to use this technology. Therefore, VR could be a way to overcome mentioned problems, i.e. inability to reproduce certain situations, and provide the users with the realistic learning experience on a very different topics, without the danger of material damages or injuries.

The focus of this thesis is to evaluate the necessary steps and requirements for building Virtual Reality tutorials for an industrial training within a company. It will research the benefits of this approach as well as the costs and the downsides of development. Additionally, it will identify the recurring tasks for the solution development that can be generalized and reused in the future.

2. Related work

An idea to use Virtual Reality technology to improve prospects of education and training is not a new concept. Joseph Psozka has already in 1995 published a paper summarizing expected future benefits of VR technology. He focused on how immersion, as a key added value of VR, would open up new possibilities in knowledge transfer. According to him "the engagement and excitement that is part of the VR phenomenon is an obvious candidate for exploitation in education and training" [22]. Furthermore, J. Psozka indicated already existing early experiments with educational VR which included indoor and outdoor navigation, simple skills training and simulation training.

In recent years, the Virtual Reality training has become popular in an education of maintenance workers for an industrial equipment. Researchers from the University of Vigo [6] explored feasibility of transforming Computer Aided Design (CAD) to VR models suitable for interactive training processes. Lin, Ye, Duffy and Su [7] presented an architecture of VR-based training systems, "systems that allow trainees to properly operate new equipment before it is actually installed". They conducted a user study where the participants had to perform simple tasks based on either user manuals or being shown VR training on the same topic. The study confirms "strong positive transfer from a virtual training environment to real-world tasks". Additional interesting result was that procedural skill tasks improved drastically within VR training while motor skill and simple tasks did not show significant changes over user manuals' methods.

In the similar study, Peniche, Diaz, Trefftz and Paramo [2] measured performance differences between trainees which needed to perform mechanical assembly tasks on the industrial sector equipment. They concluded that VR can efficiently replace a major part of a training process with the real equipment since immersive systems learning effect was nearly as good as an actual real-world training. This results have been confirmed by Prinz, Schleyer and Kurth [19] who showed that the average task performance time has been reduced 28% with the VR training and 38% with real training compared to the task execution without any previous training. In addition to mentioned efficiency, they have further measured effectiveness of VR training by comparing reduction amount of errors produces after real-world training, which was 17%, and VR training, which was even 50% reduced.

This educational and training benefits of VR technology are already noticed and utilized in industry. A practical testing and production of VR training material has increased in recent years. Certain companies focus on implementing Virtual Reality training as an industrial product [24] [25]. Others, like Simens, have invested into building their own internal development pipeline for producing multiple educational and training VR tutorials [23]. With the growing popularity of this technology on the market, it is interesting to

2. Related work

observe the costs, challenges and limitations faced when implementing VR tutorials and how beneficial they indeed are to the company and its employees with more complex and diverse course thematic.

3. Thesis focus and proposed approach

To evaluate the benefits and downsides of using VR in an industrial education and its development costs, it is decided to evaluate the process of developing one example of a virtual tutorial. The choice is to redesign an existing industrial course "High Voltage Electric Vehicle Security". In the course, the employees learn in which way to safely disconnect high voltage components inside the electric vehicles, a procedural, more complex task. It can be life threatening for an employee to touch any of the high voltage components in the vehicle before it was disconnected. Therefore, a safety critical situation is an additional, interesting aspect within the selected course content.

The VR tutorial is implemented from scratch. This is a first, education, virtual tutorial implemented within the company; there have been no previous internal resources or research to base this work on. In this regard, the project is a starting point for identifying necessary requirements and adequate approaches for building this type of virtual tutorials, design of the first virtual models and reusable functionalities. It is additionally a measure of necessary investment for the company to start with this type of internal training pipeline. The technical specifications and the review of software and hardware choices can be found in the chapter 3.2 while the functionalities which could be reused for development of another tutorials in the future are summarized in the chapter 7.

The VR tutorial is tested with the company employees to obtain their feedback and experiences. This user study, summarized in part III of the thesis, is conducted exactly with the target audience for this kind of applications in order to realistically measure the benefit of this hands on approach compared to the investment necessary to create this software solution. Additionally, it is necessary to observe if the employees could adjust to this technology and if the realistic VR experience has positive consequences on their work performance as expected, or if they might find it overwhelming and distracting from the course content.

3.1. Virtual Reality setup

The VR application needs to be set up in the room where it is safe to map the virtual world to the real world environment. The users need enough space to experiment in the VR without running into the physical barriers. One of the first questions is if the application should be designed to support only seated and standing VR experiences or also a room-scale.

In the seated VR [10] the user is experiencing virtual reality in a sitting down position.

A chair is commonly used for comfort and the user more often uses mouse and keyboard or a gamepad instead of motion-based controllers. In standing VR [28] the user is standing up in a specific area, but not moving around. He most often uses motion controllers in this kind of experience and a sensor is required to provide a tracking system. Finally, room-scale VR is an experience which "allows users to freely walk around a play area, with their real-life motion reflected in the VR environment"[27].

Since the user works with a model of an electric vehicle in the virtual tutorial, the seating VR solution would not match the problem description. Standing VR configuration is possible, but enabling physically movement which will be mapped in the virtual space would more closely replicate real-world situation and make the virtual environment seem more realistic. Therefore, this application is running with the room-scale setup.

In the VR tutorial the user is placed in a virtual garage modeled accordingly to the electric vehicles' work spaces. The real dimensions of this space are much bigger than normal office room and would be problematic to fit inside most of the convenient rooms for conducting the virtual reality training. To enable the user certain amount of moving freedom in the virtual space but also be able to organize the tutorial within the rooms of limited size, the application benefits from the teleportation strategies within the room-scale VR setup.

3.2. Technical specifications of the project

This project is implemented as a local solution and it does not need an internet connection to run. It can be easily transported and set up in any room without the need for wifi. To build a high quality performance realistic experience in the VR, in real time, an application has to run on a powerful PC with a strong graphical card. A headset with the six-degrees-of-freedom (6DOF) was necessary for accurate position and motion tracking within this type of application.

3.2.1. Head mounted display selection

The application is running on the tethered VR headset connected to the local PC. The three virtual reality platforms that are currently popular on the market are: HTC Vive, Oculus Rift and Windows Mixed Reality (WMR) headset. The readily available headsets in the company are HTC Vive and WMR, compared in this chapter.

The HTC Vive [11] package includes a headset (Fig 3.1a), two hand-tracking controllers and two wireless based tracking stations. The tracking stations can be positioned at the opposite sides of the room and create the room-scale play area the maximal size of 4.5 square meters. The minimum size of play area for the room-scale is 1.5 x 2 meters. The stations allow precise, 360 degree headset and controller tracking. The headset resolution is 2160 x 1200 pixels while the field of view is 110 degrees. The interpupillary distance (IPD), the

distance between the center of the pupils in human eyes, is mechanically adjusted on the Vive headset. The market price is 600 euros.

Windows Mixed Reality headset (Fig 3.1b) comes only with a pair of motion controllers. The Microsoft's system uses a camera on the top of a headset to track the controllers so the tracking stations are not necessary. For the room-scale experience the play area has to be defined with minimum size of 1.5 x 2 meters while the maximum boundary size is 5.7 square meters. The WMR headset in question is Dell Visor [17] with the resolution of 2880 x 1440 and the field of view of 105 degrees. The price of this headset is 300 euros.



(a) HTC Vive headset



(b) Windows Mixed Reality headset

Figure 3.1.: The virtual reality headsets

The motion tracking controllers that accompany HTC Vive (Fig 3.2a) have a Micro-USB charging port. The controller's battery can last for approximately six hours before it needs to be recharged. The Vive controllers utilize tracked motion control from the lighthouse stations, which means they can be tracked anywhere within defined space only after wireless stations are setup in the room. On the other hand, the WMR controllers (Fig 3.2b) are tracked with the sensors in the immersive headset and do not require any additional hardware to be positioned in the room previously. However, they can only be tracked when they are in the headset field of view. They need four AA batteries to be power up and their life span is about eight hours.

Based on the given comparison, WMR was better choice. The VR course should not have a dedicated room, but it should be easily transferred and held in different areas and facilities. Therefore, less necessary hardware to run the application as well as easier setup was the biggest benefit of this headset. Another important point was that WMR has better headset resolution which would enable better readability of textual content within the course. It is also more affordable solution regarding the price of the hardware. The negative aspects relate to the controllers. The user will lose tracking of the controllers when they are not in the field of view and AA batteries are less convenient solution than rechargability via Micro-USB.

More detailed comparison between these two headsets including also a comparison to



Figure 3.2.: The virtual reality motion controllers

the Oculus Rift, which was not mentioned here, is available by Jared Newman and Brad Chacos [18].

3.2.2. Software

Depending on the virtual reality platform selection there are different software solutions to consider. The HTC Vive headset is directly compatible with SteamVR platform, Oculus Rift uses Oculus home and Windows Mixed Reality officially connects to Windows's 10 Windows Store. However both Oculus Rift and Windows Mixed Reality support also SteamVR. The compatibility between platforms and headsets is shown on Fig 3.3.

Since SteamVR platform is compatible with any of the virtual reality headsets, it is the first external library used for the implementation of this project. Therefore, even though the solution is built and tested with the WMR headset with minor modifications the project will work with other headsets. In the chapter 4.2 the WMR controllers are taken as an example for the explanation of the software functionality, but the reader should bear in mind that the same setup would work with HTC Vive controllers with small adjustment to the controller's difference in shape and size.

3.2.3. Choice of the developing tool

Two main game engines that support the development of Virtual Reality software for any of the three above mentioned tethered VR headsets are Unreal Engine and Unity3D. In the beginning of this thesis short testing was conducted to determine which tool is better suited for the development of this type of virtual tutorials. The testing included theoretical

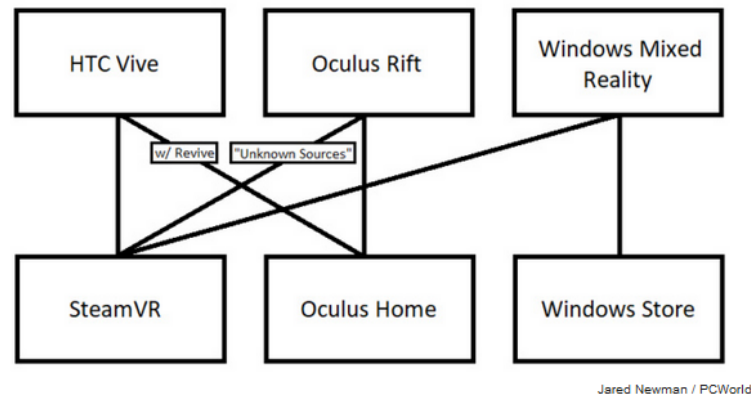
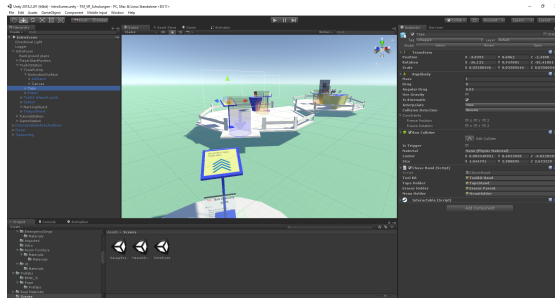


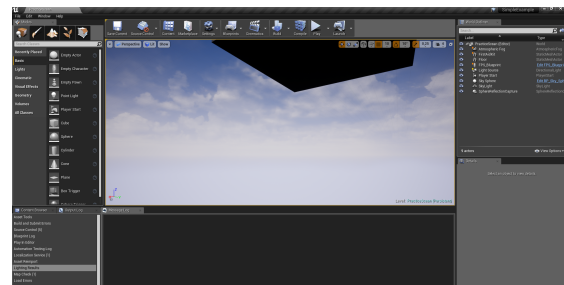
Figure 3.3.: Compatibility graph between VR headsets and software platforms [18]

research but also producing simple identical game in both game engines. The modeling tool used is Blender and compatibility with it was a part of the engine selection criteria.

Unity game engine [26] is one of the most popular game development engines released in 2005 by Unity Technologies. The main development language is C#. In Unity every functionality is implemented via C# scripts and it is focused on programming. It is suited to build mobile, desk, web and console platforms. It has a vast community of developers which provide extensive support and well equipped asset store [5]. Unity editor (Fig 3.4a) is much simpler to master for beginners in game development or virtual reality development. However, Unity graphics are not optimized and it requires extra work to make materials, textures and lighting optimal within the applications. All Blender files can be directly imported in Unity.



(a) Unity editor



(b) Unreal Engine 4 editor

Figure 3.4.: The game engine editors

Unreal engine [1] is a game engine attributed to the majority of high powered games with exceptional graphic. It has been produced by Epic Games. Unreal Engine supports only C++ development language, but the development technology includes Blueprint vi-

3. Thesis focus and proposed approach

sual scripting system. Functionality development in Unreal can be based both on C++ code or Blueprints and it is more complex task to implement simple functions. The Unreal editor (Fig 3.4b) has higher learning curve for beginners and since the engine is used mostly by advanced, professional game developers the community support is limited for beginners. In Unreal it is easier to construct complex materials and lighting is already optimized for better visual effects. Blender files must be exported to .fbx format before they can be used in Unreal.

In summary, Unity engine focuses more on providing easy and simple functionality implementations, it has very good community support and a lot of already existing free components within asset store. On the other hand, Unreal is better for producing high quality graphics and amazing visual 3D experiences but the functionality implementation is more complex and time consuming. The community support is focused on advanced professionals. Since the focus of this virtual tutorial is on the functionality implementation and user understanding rather than visual effects of the product Unity is the better engine choice.

In the table bellow the advantages and disadvantages of both game engines have been summarized for better visualization.

Comparison of Unity vs Unreal engine		
Feature	Unity	Unreal Engine 4
Blender compatibility	direct import	export to .fbx needed
Visual effects	not optimized	highly optimized
Coding	C# main language	C++ / Blueprint scripting
Functionality	easy implementation	more complicated
Community support	very good	for advanced professionals
Learning curve	low	high
Selected engine: Unity		

Part II.

Thesis implementation and realization

4. Intro room in Virtual Reality

The user will start the virtual tutorial in the VR intro room. It is an unrealistic, colourful and comic-style environment that serves as a safe place for the user to get familiar and comfortable with the VR technology. The focus is to give a short, easy and simple introduction to the use of the VR controllers, application specific commands and the background knowledge necessary for the later task execution.

4.1. Motivation

The first part of the current "High Voltage Electric Vehicle Security" course consists of a PDF presentation that will give background knowledge to an employee about the necessary safety measures inside the working garage room. The employee has to know how to identify, find and use objects, like fire extinguishers or electricity safety hooks, and information protocols like meeting place map or alarm plan. Inside the reconstructed virtual garage room, the user will have to perform the task of finding and identifying the mentioned relevant objects. This is supposed to test his understanding of the material and improve the memorization of the course.

4.1.1. First UI challenges

The challenge of designing the user interface is to provide enough information to the user about the objects he is looking for and their use without cluttering him with too much unnecessary information or breaking the immersion. The difficulty lies in the fact that the course participants could have very different background knowledge in this area. They would need to be able to get additional help and information, but also skip it easily.

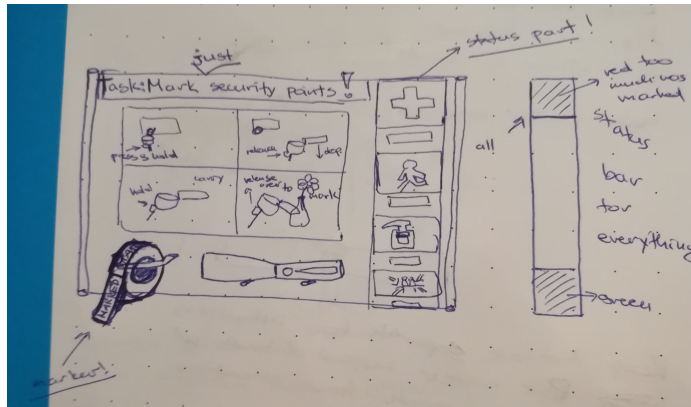
Secondly, the target audience contains people who might not have any prior Virtual Reality or gaming experience. They might never even need to use Virtual Reality again after completing this tutorial. Therefore, they need to understand how to interact and work inside this virtual environment fast and easily and without too much constrain, so that it does not take their focus from the actual learning task - the content of the VR course.

4.1.2. Early design decisions

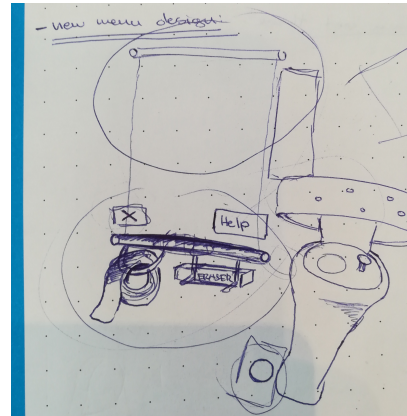
Initial research into existing Virtual Reality UI concepts brought up the idea to design a menu. The menu can be a world object attached to the VR controllers. It can be opened up and closed at any point by an action simple to remember and access, but which the

4. Intro room in Virtual Reality

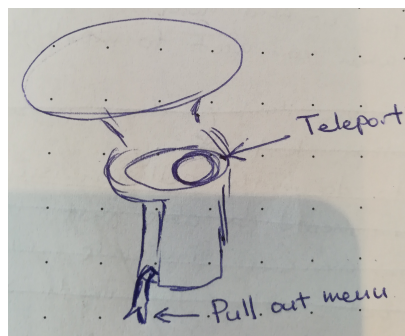
user will not trigger accidentally. This could be a small floating button attached to the controllers, as represented by [20] for the leap motion user interface system for the Virtual Reality. All the necessary information, instructions and tools should be placed inside the menu. Low fidelity mockups are provided on (Fig 4.1).



(a) First menu design



(b) Second menu design



(c) Menu opening icon attached to the controller

Figure 4.1.: Low fidelity mock-ups for first menu designs

The menu content has a simple design. It always has a clear indication of the task and a description in the form of a short text explanation or a picture. The list of objects that the user should find inside the garage room are presented only in the text form. This way, the user would have to know the names of the objects and their purpose in order to be able to recognize them inside this list of security objects. Since the menu is just meant as a reminder, it should not be comfortable for the user to keep the menu open for a long time. Therefore, the user can open up the menu by holding trigger buttons of both controllers at the same time. This triggers the opening of the menu between the two controllers.

Additionally, accessing the tools from the sketched menu design is a complicated and

unnatural action. In the following menu version, the tools have instead been redesigned around the controllers and the menu has been freed only for instructions. This menu implementation is shown on the (Fig 4.2).

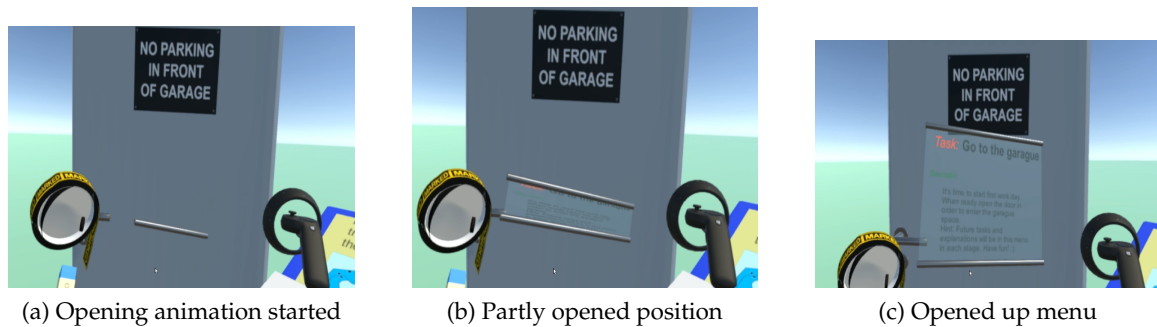


Figure 4.2.: Opening up of implemented menu with controllers' trigger buttons

4.1.3. User feedback and redesign

During the first user demo, the menu design got negative feedback. The introduction information was too crowded inside the limited menu space. It was complicated for the user to understand and follow the tasks and the opening command was hard to remember.

New information arose, the introduction to the security signs should also be part of the VR tutorial. Finally, the user should not be pressed to perform the tasks inside VR without having a no pressure place to get familiar with the interactions first.

As a solution to the mentioned problems, the VR intro room is created. It is a starting place of the tutorial where all the necessary information will be gradually provided to the user, both regarding the VR commands and the security elements specific to this tutorial.

4.2. Controllers' buttons functionality

The VR controllers are hardware additions that represent the user's hands in Virtual Reality. The VR motion controllers for the Mix-Reality headset [21] allow position tracking when they are in the user's field of view (Fig 4.3a). They are the first tools used for interaction within the virtual tutorial.

Each controller has six different buttons: the trigger button, the touchpad, the thumbstick, the menu button, the Windows button and the grab button (Fig 4.3b). In order to simplify the VR tutorial, I decided to use the minimum amount of buttons for the interactions. Only two buttons are relevant: the touchpad, which is used to move around the virtual world with teleportation, and the trigger button, which is used for all other object interactions. However, the Windows buttons' original functionality is not overwritten:

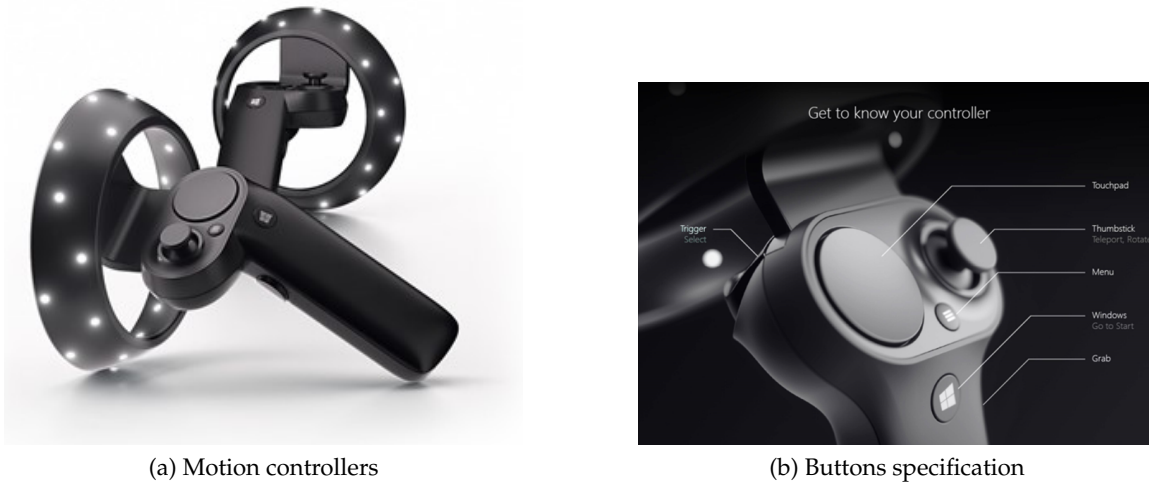


Figure 4.3.: Windows Mixed Reality motion controllers [21]

with the press of the Windows button the user will leave the VR tutorial application and find himself in the default Microsoft Mixed-Reality-Portal room.

4.3. Marking toolkit

In the intro room, the user gets to know the security objects. He needs to be aware of the location and function of these objects in the garage room. Therefore, he will be asked to find and mark these objects.

The user is provided with the marking toolkit inside the intro room. The marking toolkit consists of a marking tape and an eraser (Fig 4.4). The marking tape is positioned on top of one of the VR controllers matching to controller's circular shape. The eraser is placed on the other end of the controller like it would be at the end of a pencil.

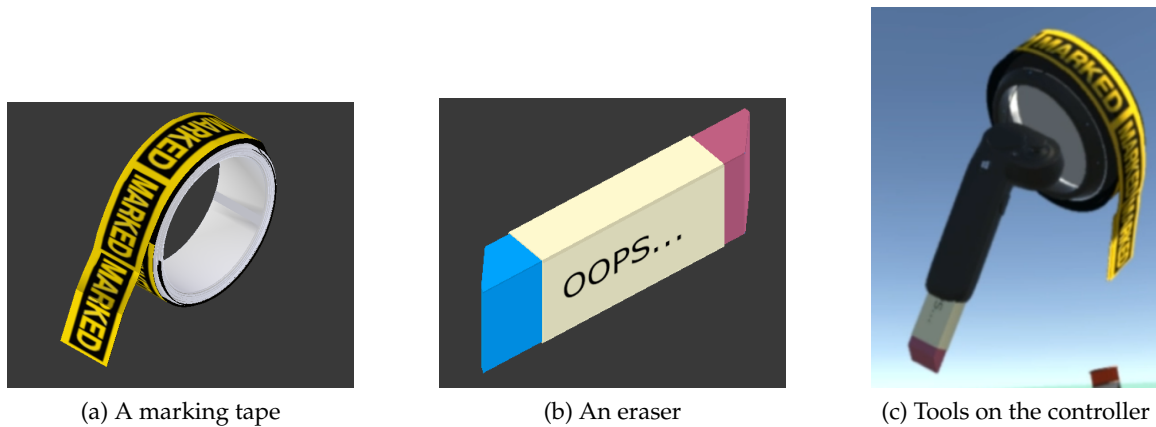


Figure 4.4.: Marking toolkit

The indication that the specific object is marked is the fixed-placed yellow-and-black piece of the marking tape on the object surface (Fig 4.5). The user must touch an object with the marking tape in order to put the "marked" label on it. In case the user has marked the wrong object, he is able to remove the marking by touching the object with the eraser. The eraser will remove the marked tape and reset the state of the object to not marked.

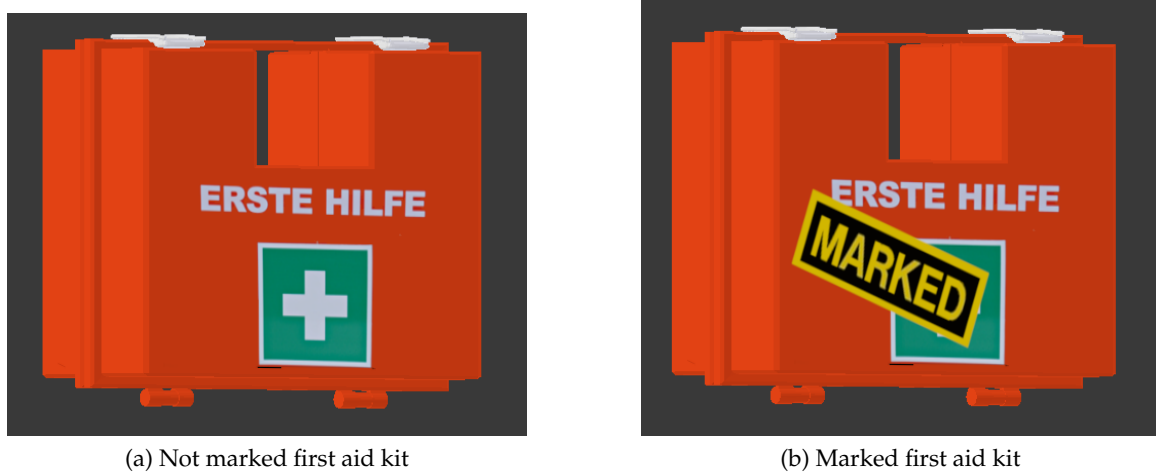


Figure 4.5.: Example of the marked virtual object

4.4. Intro room stations

The user has to pass the set of stations in the VR intro room. Each station is equipped with simple tasks meant to gradually ease the user into VR and provide him with the necessary background knowledge for completing the tutorial.

On each of the stations the user will find an instruction stand. Each stand contains a short and simple textual explanation of the task with an accompanying animation. The video animations remove the need for unnecessary and usually boring text that the user would otherwise have to read. The pictures represent a universal way of providing instructions and information independent of the language.

4.4.1. Start up station

The user starts the tutorial on an oval disk surface. He needs to use the teleporting function in order to reach the next island since there is no bridge to it. The instruction surface stand contains the indication that the teleporting is done with the use of the VR controllers (Fig 4.6a). Once the user looks at the controllers, he sees that the touchpad button has been marked yellow and labeled "Teleport". With the press of the touchpad button, teleporting points in the VR tutorial will become visible, marking the movement possibilities for teleporting (Fig 4.6b). At this point in the tutorial, the user can teleport just to the toolkit station since he is required to complete the stations in order.

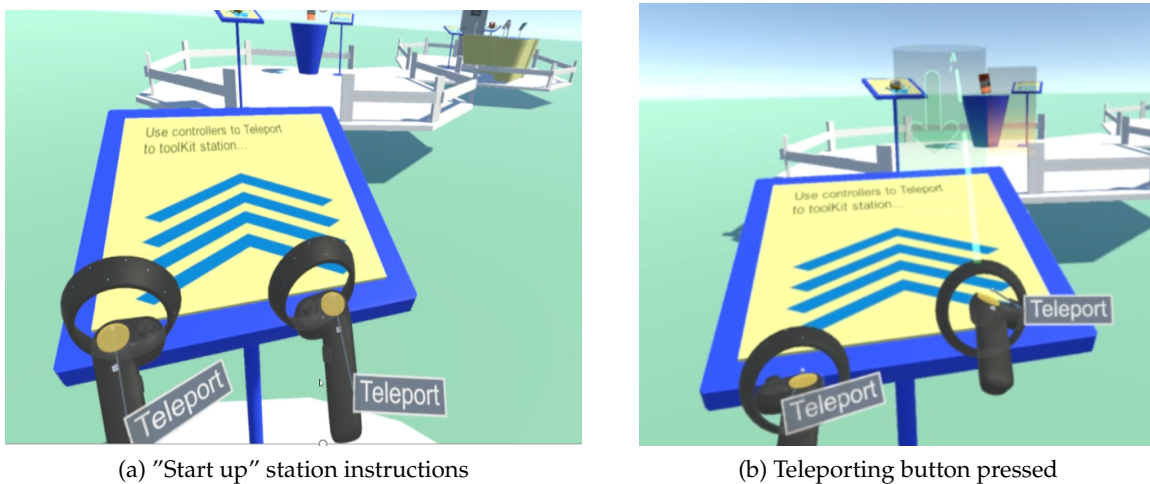
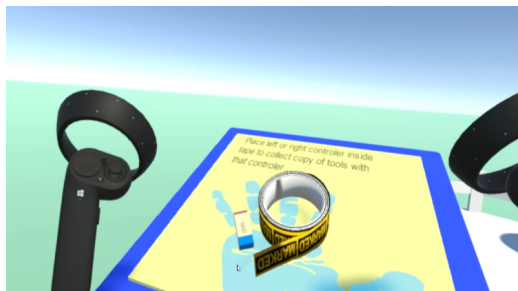


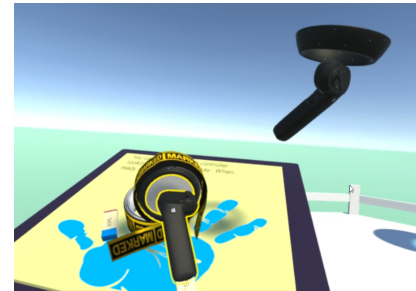
Figure 4.6.: "Start up" station for introducing the teleporting functionality to the user

4.4.2. Toolkit selection station

Next station gives the user an opportunity to choose which controller he prefers to have the marking toolkit on. The instruction holds a copy of the marking tape and the eraser (Fig 4.7). He can pick them up by touching them with either of the controllers. The controller that touched the tape is the one equipped with the marking toolkit. If the user wants to change the selected controller, he just has to touch the copy of the tape with the second controller.



(a) A copy of the marking tape and the eraser

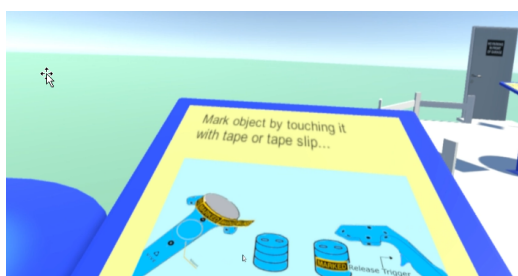


(b) Picking up the toolkit with the left controller

Figure 4.7.: "Toolkit selection" station

4.4.3. Marking intro station

When the user has equipped one of the controllers with the marking toolkit, he has to learn how to use these tools. This information will be given to him on the introduction to the "object marking" station. This station contains an instruction stand and a table with the barrel object placed on it.



(a) Instructions on how to mark the object



(b) Marking an example object

Figure 4.8.: "Object marking" station - Mark the object

The instruction stand contains two short animations. The first animation explains that the user is able to mark the example barrel object by touching it with the marking tape (Fig 4.8). When the user performs this action, the barrel is marked and the instruction stand continues to the second animation.

The second animation explains that the user is supposed to remove the marking from the barrel with the eraser (Fig 4.9a and Fig 4.9b). When the user has removed the marking, he still can mark the barrel or remove the marking as many times as he wants. However, he accomplished both tasks at least once successfully and is allowed to proceed to the next station (Fig 4.9c).

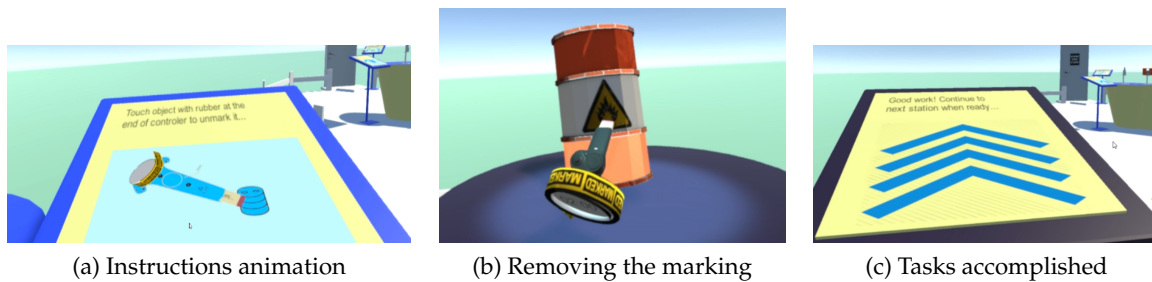


Figure 4.9.: "Object marking" station - Remove the marking

4.4.4. Security objects introduction table

The intro room gives the user a background information on the relevant security objects. The users can have different familiarity level with them depending on their background. Therefore, an exhibition table is introduced.

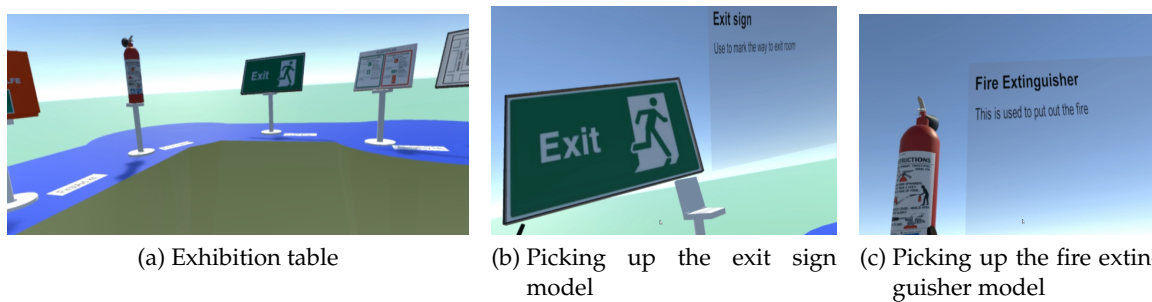


Figure 4.10.: Exhibition table with the security objects

On the table (Fig 4.10a) the miniature version of every relevant security object (refer to chapter 5.3) is displayed together with the name tags underneath the model. The user is able to see all the objects at the same time and read what they are. He can also pick up any

of the objects from this table. If the user picks up one object, detailed information about it is displayed on the plane next to the object (Fig 4.10b and Fig 4.10c). This way, the user can choose the objects he wants to familiarize with and only spend time on these, while skipping the ones he already knows. He is able to spend as much time as necessary at the exhibition table and then continue to the next station once he is comfortable with his knowledge.

4.4.5. Garage entering station

Finally, the user teleports himself to the last station. This station is the entry point to the garage room. The instruction stand will indicate that the user should open the garage room door in order to finish with the intro room and start with the actual tutorial tasks (Fig 4.11). By turning the door handle, the user activates the level transition and is loaded into the garage room.

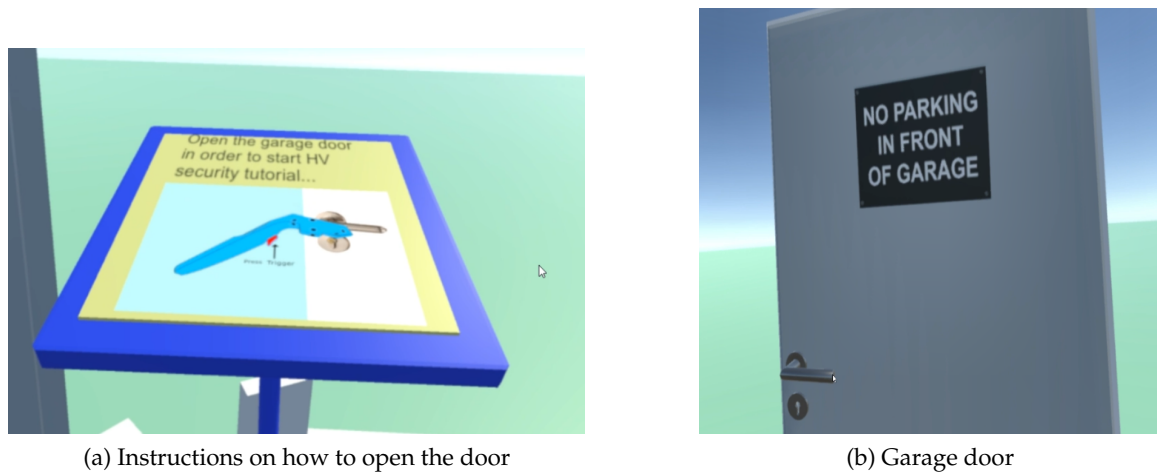


Figure 4.11.: Garage door as an entry to the garage room tutorial

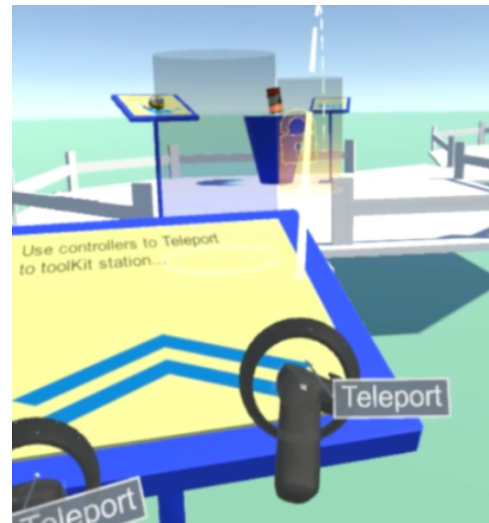
4.5. Colour coding of the stations

Each of the described stations contains a teleport point. Teleport points is locked and glows yellow until the necessary conditions have been met (Fig 4.12). Since the user is required to complete the intro room stations in the specified order, he is able to teleport only after he has completed the required tasks on the current station and only one station forward.

The stations are colour coded in order to provide clear feedback to the user at which point he has successfully performed the tasks on the current station and unlocked the next station. The successful accomplishment of the task on the current station will cause it



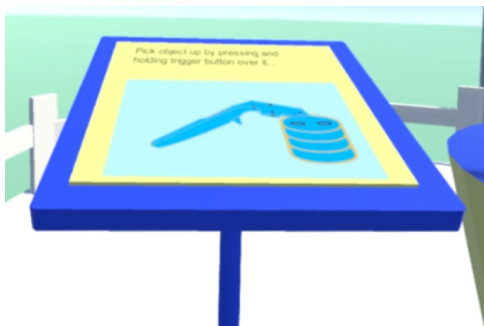
(a) Unlocked teleport point glows green



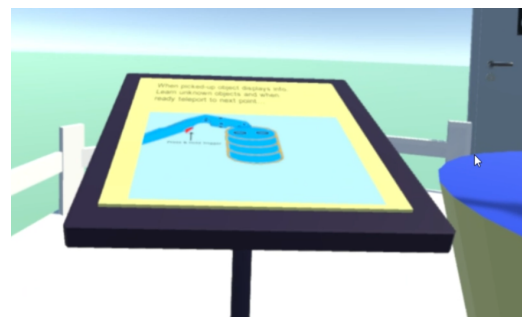
(b) Locked teleport point glows yellow

Figure 4.12.: Locked and unlocked teleport points

to change the background colour from blue to the dark purple (Fig 4.13). All completed stations are dark purple, while the once left to complete are blue. The user is able to return to any completed station except for the first one.



(a) Not completed station is blue



(b) Completed station is dark purple

Figure 4.13.: Colour coding of the intro room stations

5. Garage room and the objects marking

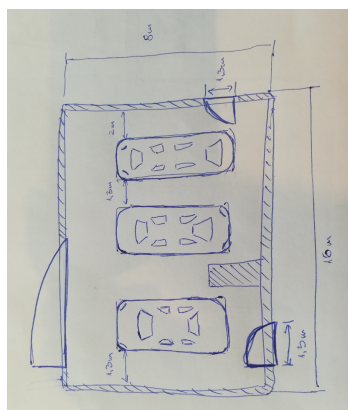
The current "High Voltage Electric Vehicle Security" course starts with a PDF presentation as an introduction to the security measures. The employee has to be aware of these before he is allowed to start working with the electric vehicles stationed in the garage.

In this virtual tutorial, the user is required to identify and mark all of the safety measure elements inside the virtual garage. This task trains the user to be more likely to find the same objects in the real garage space, when he is for the first time introduced to his work place.

5.1. Static room setup

The virtual garage room is modeled based on an actual working garage space for employees. By making the virtual room look more realistic and similar to the real world situation without losing generality, the user is able to gain more valuable experience and remember details from the virtual tutorial that he can later apply in his work.

The room has been designed as a simple rectangular room with only one wall extension, providing a certain amount of occlusion. It has parking spaces for three electric vehicle models. However, only one vehicle is actually present inside the room. Refer to the low-fidelity drawing (Fig 5.1a) and the room implementation in the Unity editor (Fig 5.1b).



(a) Garage room drawing



(b) Garage room implementation

Figure 5.1.: Garage room mock-up drawings and Unity implementation

In the garage room, the user can interact with every object. The interaction can be picking the object up and moving it, marking it and removing the marking from its surface, or activating opening and closing animations. If the user is able to mark almost every object in the room (just like he could in the real life) he has to pay more attention to the objects and decide if they are the security objects that should be marked or not. Therefore, the task of marking an object is much more complex than only testing which ones can be marked within the VR application.

Most objects in the VR garage are defined as standard "Throwables", see section 7.1.1. They can be picked up, moved and thrown around the room. The objects attached to the wall can be divided into two groups: "Attachable throwables" and fixed objects. "Attachable throwables", see section 7.1.2, can also be picked up from the wall and thrown around the room, but if they are again placed in their original position they will attach back to where they have been before. Fixed objects on the other hand are pictures and stickers and they should not be taken from the wall. That would only be a distraction since they are flat and light weighted and don't belong anywhere else in the room. Therefore, fixed objects can only be interacted with but not moved from their original position.

5.2. Garage room instruction stand

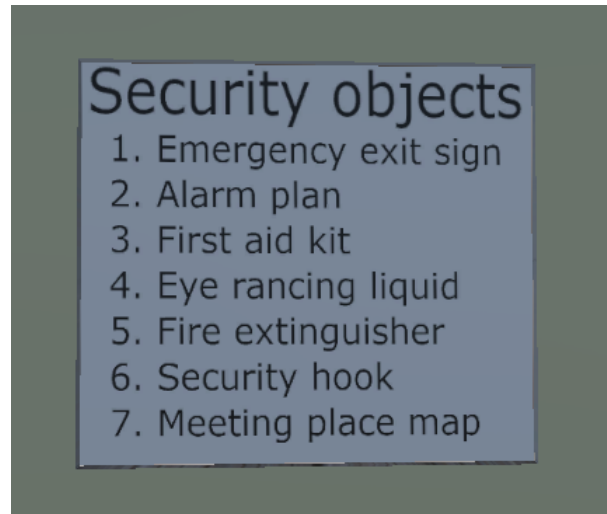
When the user enters the virtual garage space, he should get a clear task description. In his VR intro room experience, the instructions are provided on the instruction stands. Following the same logic, the user is given one last instruction stand at the entry of the garage room.

The instruction stand (Fig 5.2a) contains only a textual task description. It informs the user that he should mark only security objects inside the room but take care not to miss any. If he needs a reminder of the objects needed to be marked, he is able to find it on the picture on the wall when he looks to his left from the starting position (Fig 5.2b). Finally, the user should press the "START" button on the instruction stand when he is ready to proceed with the task.

When the "START" button is pressed, the instruction stand drops through the ground. The user is provided with the marking toolkit and the teleporting option, which were disabled until this point inside the garage room.



(a) Instruction stand at the garage room entry



(b) Reminder list with the security objects' names

Figure 5.2.: Marking task description components

5.3. Security measures

The necessary security measures in the garage room include knowledge of the location and usage of the safety objects, and familiarity with the emergency protocols and how to proceed in case of an extraordinary situation. Safety objects include:

- first aid kits
- fire extinguishers
- eyewash liquids
- safety rescue hooks

The information on how to proceed in case of an emergency is provided on an alarm plan and an evacuation plan (exit signs and meeting place map).

5.3.1. A First Aid kit and an Eyewash liquid

The first group of safety objects is used to provide an immediate medical help in case of an accident at the work place. The employee has to know how to help injured coworkers or treat his own minor injuries. For this purpose, each garage room should be equipped with a first aid kit and an eyewash liquid.

5. Garage room and the objects marking

The first aid kit is a collection of essential medical supplies, including bandages for wound treatment, antiseptics and simple medication. It is often packed inside a plastic box containers and positioned on the wall. First aid kits can be identified by a green background sign with the white cross in the middle (Fig 5.3a).

Eyewash liquid (Fig 5.3b) is a saline solution bottle used to rinse out the eyes. In case foreign particles or chemicals get into the employee's eyes while working, he should immediately clean them with this liquid and only afterwards look for further help. Sometimes, small eyewash liquid bottle can be found inside the first aid kit box.



(a) First aid kit box



(b) Eyewash liquid bottle

Figure 5.3.: Security objects for providing an immediate medical help

5.3.2. A fire extinguisher and a safety rescue hook

The second group of security objects is dedicated to the objects used to fight against hazardous situations. In case there is an emergency situation at the work place, like electrical shocks or fire, it can be controlled or stopped by an employee with the adequate tools.

Every garage space has to be equipped with fire extinguishers. They are used to control and stop the progress of small fires. The fire extinguisher consists of a high-pressure container with the specific handle at the top used to release the extinguishing agent inside. The handle is sealed with a pin. The user has to pull out the pin and break the tamper seal before he is able to use the fire extinguisher. The instruction steps how to use a fire extinguisher are printed on the bottle.

The safety rescue hook is a necessary protection item used to help people if they accidentally get in touch with high voltage by retrieving these victims from the electric shocks. If an employee would try to pull someone who is under the electric shock away from the source with his hands, he will also become a conductor and get electrocuted. Certain isolation materials are necessary as a bridge between a victim and a rescuer.

From the information by [15], safety rescue hooks are “made from black HD polyethylene with high temperature stabiliser additive, and 2% U.V. stabiliser for high U.V. protection.” This material will not conduct electricity, which makes the safety rescue hook a perfect item to pull someone away from high voltage without being hurt. The mentioned article also stresses the importance of the safety hooks with the new electric vehicle usage and production and their presence in these garage spaces: “Electrical voltages in electric & hybrid vehicles are significantly higher than in a regular vehicle measuring up to 650 Volts of direct current (DC). In dry conditions, accidental contact with parts that are live at voltages of about 110 Volts DC can be fatal. With the growth of electric & hybrid vehicles, safety rescue hooks should become common place in vehicle maintenance workshops.”



(a) Fire extinguisher



(b) Safety rescue hook

Figure 5.4.: Security objects for fighting the hazardous situations

5.3.3. An alarm plan, an exit sign and a meeting place map

Finally, the third group of security measures is related to finding and obtaining knowledge about the adequate procedure in case of an emergency situation. All the necessary information is provided inside every garage and it is every employee's responsibility to know how to reach it in time and act accordingly to these instructions.

An alarm plan is a paper printout containing instructions on how to proceed in case of an emergency or an accident. It is usually taped to the entry door or some other visible place in the room. It presents only a simple three step instruction that the employee must follow in the indicated order. Emergency numbers and the information of a responsible contact personnel can also be found on such a paper.

An exit sign is a clearly visible object placed next to the closest emergency exit indicating the evacuation route. It often contains the word "exit" printed on it in the local language. More recently, the word "exit" is replaced with the picture representation (Fig 5.5b).

A meeting place or assembly point is a designated place where the people should gather after they have evacuated the building in the case of an emergency. Often they are required to also report here after the evacuation so that it can be ensured that the building is really empty and everyone is accounted for.

Inside the garage room, an employee can find a map with the local street plan and clearly indicated assembly point (Fig 5.5c). The assembly point is a green background sign with white picture showing symbolic drawing of people gathering in the middle.



(a) Alarm plan



(b) Exit sign



(c) Meeting place map

Figure 5.5.: The information signs how to proceed in the case of an emergency

5.4. BMW i wallbox

The BMW i wallbox (Fig 5.6) is an electrical charging station for electric vehicles such as BMW i3. In the VR garage room, they are decorative virtual objects. They were modeled by one of the student designers in the R&D department at Magna Telemotive.

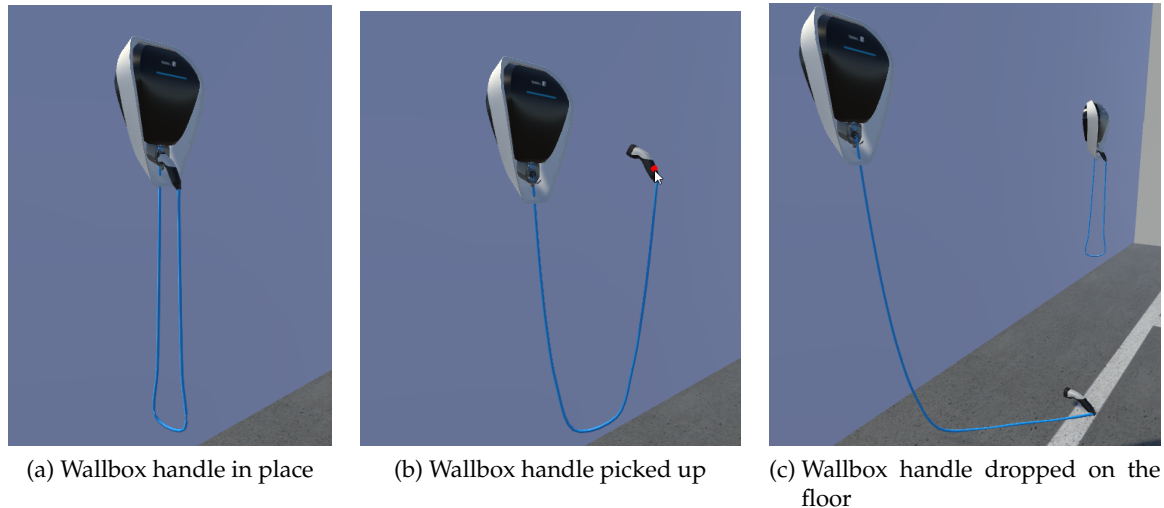


Figure 5.6.: BMW i wallbox with "Attachable throwable" handle

The standard charging cable at the wallbox is an "Interactive Cable", also designed and implemented by the same student. The cable connects the BMW i wallbox to the charging handle. The handle is defined as an "AttachableThrowable" (see chapter 7.1.2) and can be detached from the charging station, attached back or just dropped down anywhere in the room.

5.5. Marking task performance grading

When the user has read the task from the instruction stand at the garage entry (refer to chapter 5.2) and started the assignment, he is able to move around the room and mark or remove the marking from the majority of present objects. The user does not gain any feedback while performing this task. He is not rewarded for marking the correct object and he is not punished for marking the false objects. The room situation does not change even if he has correctly marked all the objects.

The trigger for continuing with the tutorial is to follow the instructions presented on the only running laptop in the virtual garage room (Fig 5.7). As indicated, the user has to confirm himself that the marking task is completed by putting the controller into the black virtual object in front of him.

5. Garage room and the objects marking

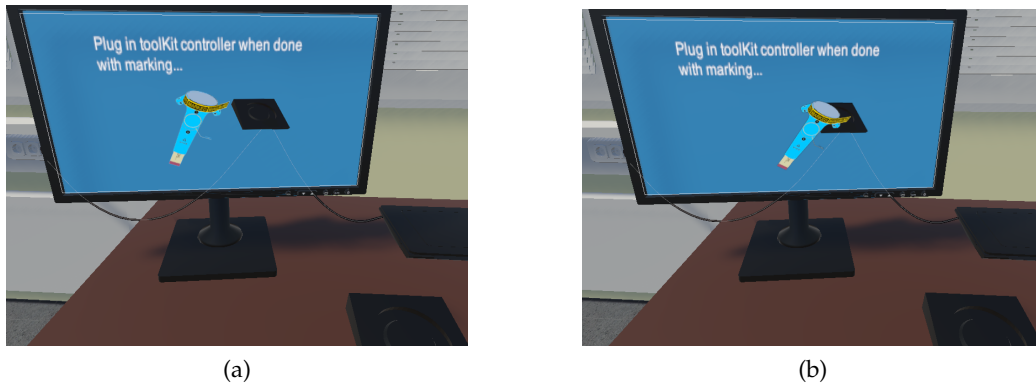


Figure 5.7.: Instructions on how to complete the marking task

Once the user has decided to take this action, he can not go back anymore. He is evaluated based on the marked objects and shown his performance as a slow running animation on the laptop. At the same time, the marking toolkit is removed from the controller since there is no use for it for the rest of the tutorial. The grading process for the user's task performance is presented on the monitor in the following order:

First, the user is evaluated whether he has found all the necessary emergency objects inside the virtual garage room. Each object's type is displayed separately with the small image icon and the name (Fig 5.8). The completion of the task is based on an all or nothing grading, meaning that only if the user has correctly found and marked all the objects of specific type group, he gains a point for it. The displayed icon will be coloured green with the "all marked" text. If the user has marked only some of the objects of this type, the object's icons appear gray with "not all marked" text.

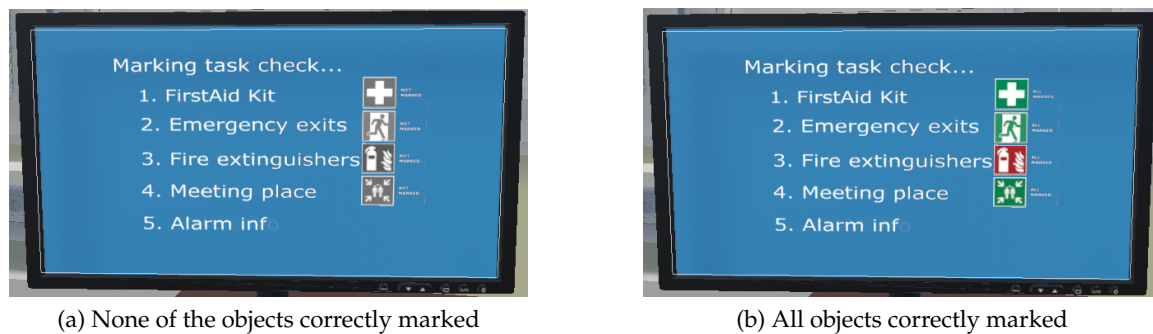
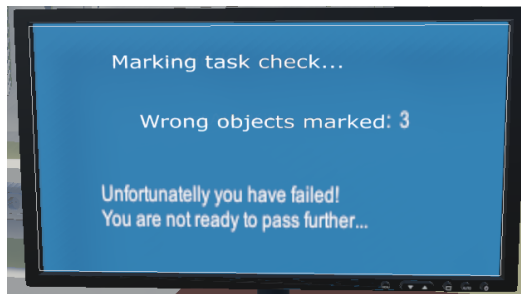


Figure 5.8.: Evaluation of the objects that should have been marked

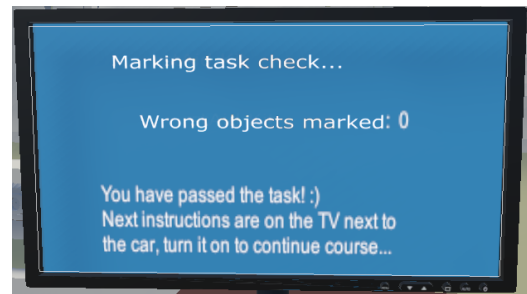
Second, the user is evaluated whether he marked any incorrect objects. The monitor only displays the amount of incorrectly marked objects without indicating their individual

names.

Finally, the user is presented with his final score. If he failed the marking task, he is required to repeat this process before he is allowed to continue with the rest of the course (Fig 5.9a). If the user passed, he is presented with the instructions on how to proceed with this virtual tutorial (Fig 5.9b). The user passed the course only if he correctly marks all the necessary security measures in the room and does not mark any of the decoy objects that do not belong to this group.



(a) Marking task failed



(b) Marking task successfully passed

Figure 5.9.: Final score indicating pass or fail of the marking task

6. Working with the vehicle

After an employee has been familiarized with the necessary safety procedures, he is ready to start working with the electric vehicle. The electric vehicle is safe to work on only after the high voltage components inside the car are disconnected. The employee has to check whether this is the case and, if not, personally disconnect the high voltage components in the vehicle before continuing with his work.

In the current version of the course, a group of employees are led to a car in the garage where the instructor will show them once the necessary steps for disconnecting high voltage components in the electric vehicle safely. These steps are also provided as a check list on a sheet of paper (Fig 6.1).

<p>Fixed activity Make sure that there is no voltage, secure and check before switching on again</p> <p>Activity: Ensure that there is no voltage on the Electrified Test Vehicle XX</p> <p>Requirement: Training as a qualified electrician for specified activities</p> <p>V-Nummer / Fahrzeug _____ HV-Arbeitsverantwortlicher _____</p> <p>Remove vehicle key <input type="checkbox"/></p> <ul style="list-style-type: none"> o Switch the car off o Switch back to terminal 0 (observe Comfort Access) o Remove vehicle key <p>Make HV voltage free <input type="checkbox"/></p> <ul style="list-style-type: none"> o Pull HV emergency (HVE), high-voltage indicator display if installed wash o Remove service disconnect (mechanical disconnection) o Press the HV emergency stop switch (not BMW i3) <p>Secure the HV system against being switched on again <input type="checkbox"/></p> <ul style="list-style-type: none"> o Store key for HV emergency stop switch o Safety store (disconnect) service disconnect with lock <p>Note building site related discharge <input type="checkbox"/></p> <ul style="list-style-type: none"> o Observation HV indicator flashing red LEDs (if installed) o Wait for discharge time up to 5 minutes <p>Disconnect 12-volt supplies <input type="checkbox"/></p> <ul style="list-style-type: none"> o Disconnect the charger / measuring equipment from the vehicle / battery o Switch off main battery switch and remove key (if installed) o Disconnect 12V battery negative lead from battery mechanically (Abschaltung nicht möglich) → Disable / Disconnect the DC / DC converter or logic plug HV memory 	<p>Secure 12-volt supply against restart <input type="checkbox"/></p> <ul style="list-style-type: none"> o Reconnect 12V battery negative lead against re-fuse e.g. EoloSchubabdeckung <p>Determine absence of voltage (all-pole) <input type="checkbox"/></p> <ul style="list-style-type: none"> o No red LEDs visible on the HV indicator o Opening a simple accessible HV component, if possible, on the component to be processed o Check the absence of voltage with 750-volt measuring device Check the function of the meter, e.g. to 12-volt battery. Observe the measuring range setting DC <p>Mark the vehicle as "de-energized" <input type="checkbox"/></p> <p>Attaching the sign "Do not switch, it is working" Interior mirror sign features a "professional power-off" with date and name</p> <p>_____ Datum, Ort, Uhrzeit</p> <p>_____ Unterschrift:</p>
---	---

Figure 6.1.: Check list for disconnecting high voltage in the electric vehicle

In this part of the virtual tutorial the employees are given an opportunity to perform these steps on their own and make mistakes inside a reconstructed virtual garage without personal safety risk. An electric vehicle BMW i3 is used for the purpose of this virtual tutorial. Instructions on how to switch off the voltage on the BMW i3 have been taken from "BMW i3 Emergency Responders guide" [8] and are explained in detail in the following sections.

6.1. BMW i3 as a 3D electric car model

The BMW i3 model's (Fig 6.2) car exterior and interior was acquired by the "Magna Tele-motive" company from "Hum3D", while the engine parts and emergency disconnect switch have been modeled by one of the student designers in the R&D department. Each of the four car doors, front and back car trunk can be opened and closed. Through the front and back car trunk the user gains access to the relevant parts for turning off the car voltage which is the goal of this virtual tutorial.

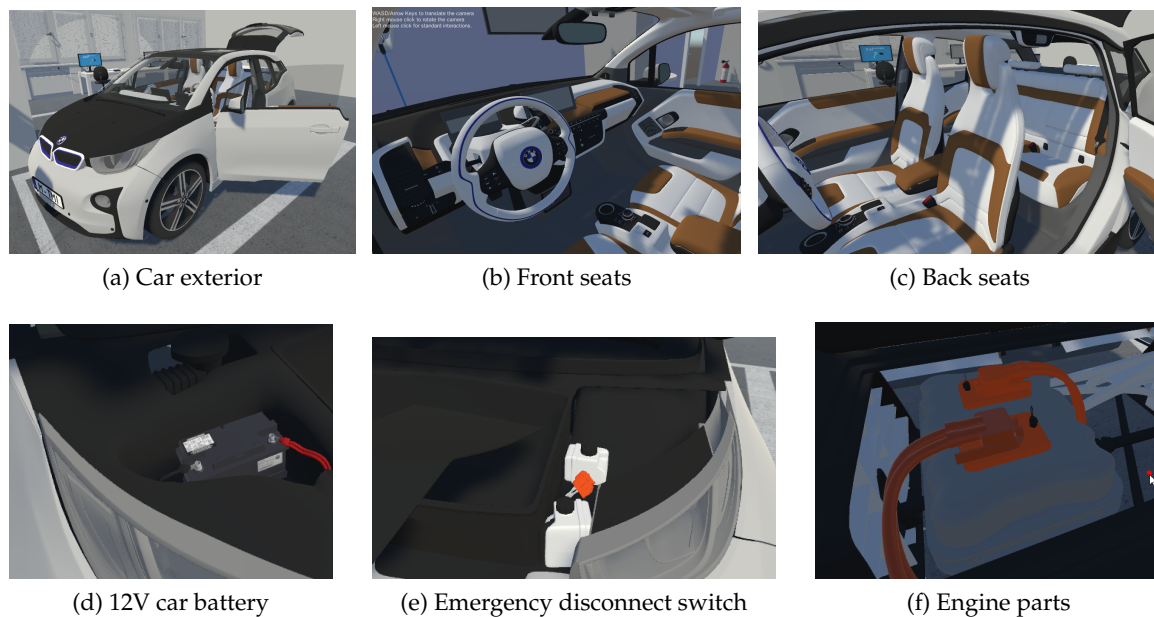


Figure 6.2.: BMW i3 car model

6.2. Instruction screen for the reminder check list

The check list on the sheet of paper that employees get in the current "High Voltage Electric Vehicle Security" course to help them disconnect high voltage components in the electric vehicles is implemented as an instruction screen in this virtual tutorial.

The instruction screen is placed next to the model of the BMW i3 (Fig 6.3a). By turning on the instruction screen, the user starts the part of the virtual tutorial dedicated to switching off the car. Once the screen is on, the list of instructions appear on the TV screen (Fig 6.3b). The TV screen is actually a touch screen. The user can expand any of the instructions to gain detailed explanation by clicking on it (Fig 6.3c). Like in the rest of the VR tutorial, instructions are picture based with short and simple text explanations.

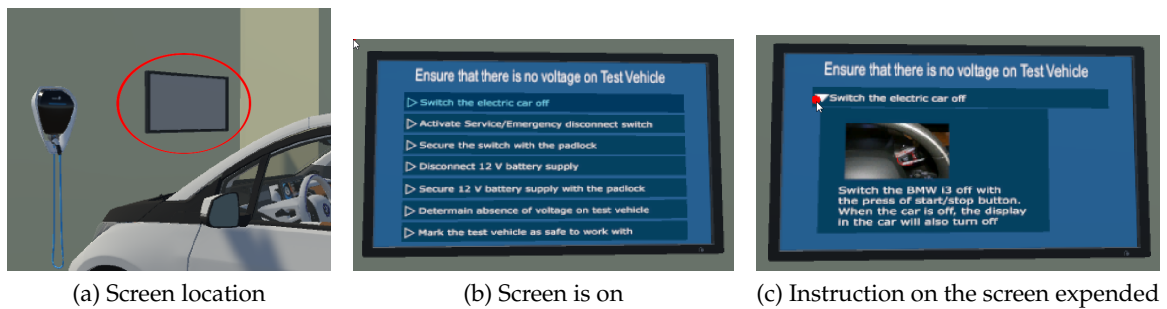


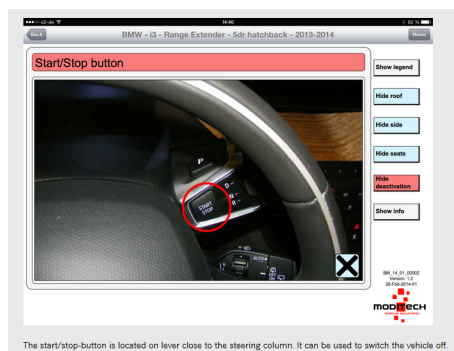
Figure 6.3.: Instruction screen for reminder check list

The user can expand or close any of the instructions at any time. He is supposed to follow the list in the specified order but he does not receive progress feedback on the instruction screen. Only after completing the tutorial or failing are his final results displayed.

6.3. Switch the electric car off

The first step in making the electric car safe to work on without the danger of electricution is to switch it off. The Start/Stop button is located on the right side of the steering wheel on the BMW i3 model (Fig 6.4a).

In the VR course the initial state of the car is "on". The user is required to switch off the car before opening the hood by pressing the Start/Stop button. The information display on the right side of the drivers seat will turn off once the car has been switched off (Fig 6.4b).



(a) Start/Stop button [8]



(b) Information display

Figure 6.4.: Start/Stop button and information display

6.4. Disconnect high voltage inside the electric car

In order to disconnect the high voltage inside the electric car, the employee has to activate an emergency disconnect switch. This stops the high voltage electric current circulation inside the car.

The emergency disconnect switch is placed in the front part of the car, underneath the car's hood. Here, the employee can identify two compartments; the emergency disconnect switch is located inside the right one marked in red (Fig 6.5a). The employee will gain access to the switch by removing the compartment cover. The emergency disconnect switch is orange, although it is not a high voltage component. It can be pulled apart in the direction of the arrow (Fig 6.5b) and pushed back into the starting state. The switch is activated when the hole is completely free. The employee uses this hole to install a padlock to prevent unintended re-activation.

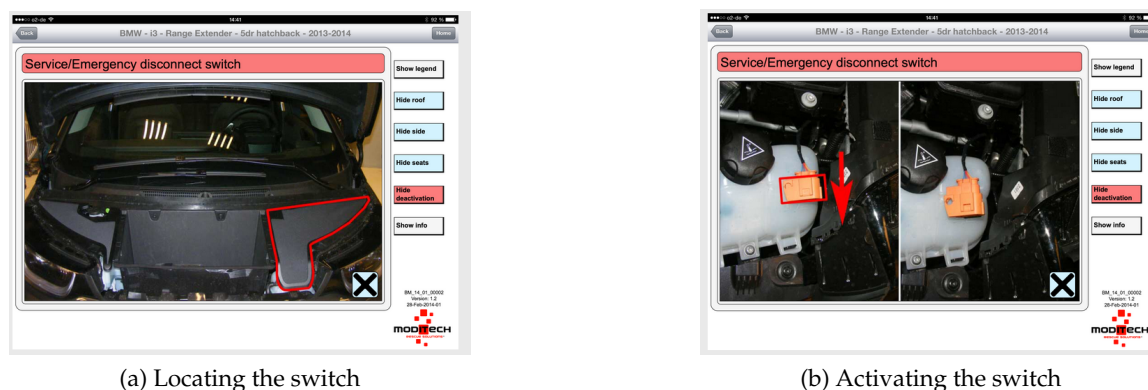


Figure 6.5.: Emergency disconnect switch [8]

6.4.1. Enabling the user to locate and identify the emergency disconnect switch

In reality, the employee has to press the hood release in order to pop open the car's hood. The hood will open up slightly, after which the employee is able to pull it upwards and open it up.

There was no need to implement the hood release inside the VR course. Instead, the user is able to interact with the BMW i3 and open up the hood (Fig 6.6a), the trunk and each of the four car doors with the controllers. Once the controller has been coloured yellow for interaction, a press of the trigger button will activate the opening and closing animations.

Under the hood of the vehicle the user can pick up the right compartment cover (Fig 6.6b), an object that is defined as "Attachable Throwable" (see chapter 7.1.2). The user is able to move the cover, placing it either on the floor, on the car's surface or just throwing it around in the room. If the user drops the cover right above its original place, it will

snap back in. When the user has removed the cover, he will be able to see and identify the emergency disconnect switch.



Figure 6.6.: Locating the emergency disconnect switch

6.4.2. Switching the emergency disconnect switch on/off with VR controllers

Once the employee has successfully found and identified the emergency disconnect switch, he can activate it. The switch is activated when it is pulled apart so that the hole is completely free.

Inside the VR tutorial, the emergency disconnect switch is a static component, therefore it cannot change position or orientation. However, the user is able to interact with the switch with the use of the VR controllers. As with any interactable virtual component, the VR controller glows yellow once it is inside switch collider area.

At this point, the user is able to grab the switch by pressing and holding the trigger button. If the controllers are moving upwards or downwards while in this state, they also drag the top of the switch with them. This either pulls the switch apart or pushes it back together with the bottom part of the switch. The switch has an uncountable amount of discrete states between its closed and open position. Therefore, the user alone is responsible to detect at which point the switch has been pulled apart enough to be activated. This provides realistic feeling of activating and deactivating the emergency disconnect switch. The switch cannot be broken and it is not possible to move it beyond its borderline positions.

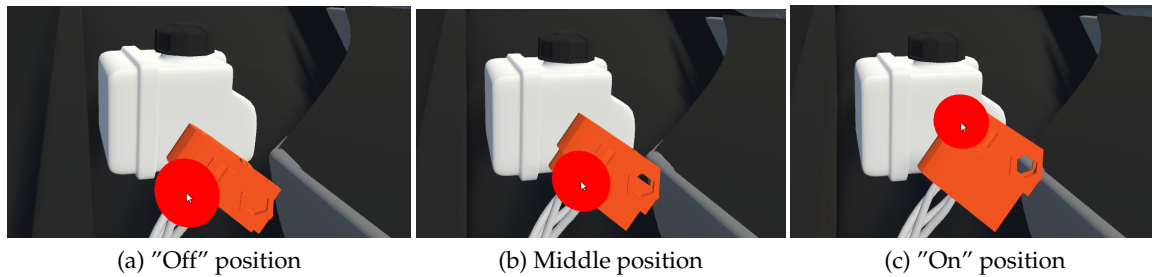


Figure 6.7.: Activating the switch with the controllers

6.4.3. Secure the emergency disconnect switch with the padlock

Once the employee has pulled the emergency disconnect switch apart, the switch activates and disables the flow of high voltage electric current through the electric car. After a small discharging period, the electric vehicle is safe to work on without the danger of high voltage. The employee places a padlock on the switch, through the hole that opened up once the switch was pulled apart, to ensure that there is no accidental re-activation of the switch.

In the tutorial, the user is required to do the same procedure. He first has to collect the padlock from the padlock control box. The padlock will open up, once it is picked up by the user. He should drop the padlock on the emergency disconnect switch in order to lock it. The padlock successfully locks the switch only if the switch is in its activated state (Fig 6.8a). Otherwise, the padlock just falls down on the car since it could not be attached to the emergency disconnect switch (Fig 6.8b).

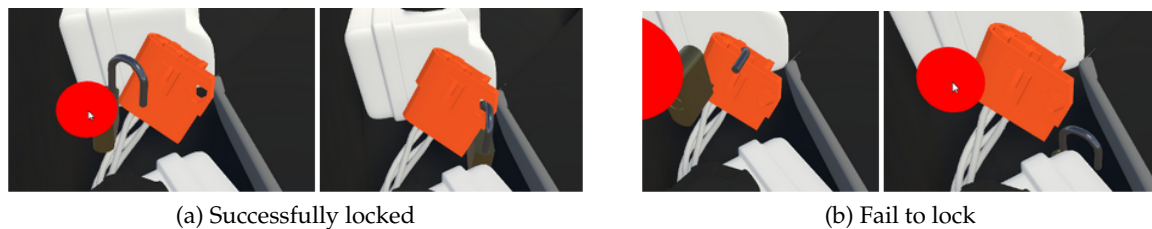


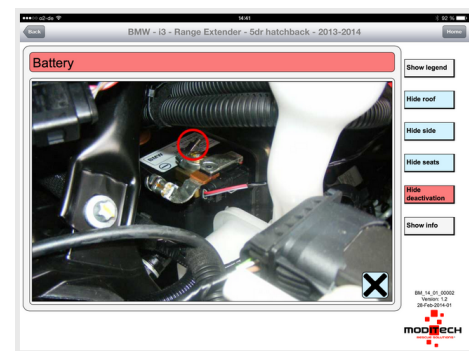
Figure 6.8.: Securing the switch with the padlock

6.5. Disconnect the 12V car battery

The 12V car battery is located in the left compartment underneath the hood of the BMW i3 (Fig 6.9a). Inside the compartment the battery is well hidden by additional wiring. The employee has to navigate to the negative battery terminal and disconnect it from the cable. He first has to loosen up the nut (Fig 6.9b) and then he is able to pull off the battery earth lead in the upwards direction. Finally, the earth lead is secured against re-attaching by placing the padlock through the ring on the top of the cable.



(a) Locating the 12V car battery



(b) Disconnecting the battery earth lead

Figure 6.9.: The 12V car battery location [8]

6.5.1. Locating the 12V car battery

In the VR course, the 12V car battery can be found inside the left compartment once the cover has been removed. The left compartment cover has the same characteristics as the right compartment cover. For more details, refer back to chapter 6.4.1.

There is no additional wiring modeled in the left compartment in the VR course. Therefore, it would be easy for the user to locate and work with the battery. The battery's negative terminal is marked with a minus sign and the black cable connecting to it is the earth lead that shall be disconnected (Fig 6.10).



Figure 6.10.: The 12V car battery model

6.5.2. Disconnecting the 12V car battery

The 12V car battery is disconnected when the earth lead is pulled away from the negative battery terminal. The earth lead can be moved only once the screw has been loosened up. The user can loosen up the screw by pressing the trigger button when the controller is interacting with its collider. By pressing the trigger button on the controller, the user will activate the opening of the screw (Fig 6.11c). The same action will tighten the screw (Fig 6.11b). Since the battery details are very sensitive and small, the user receives additional visual feedback. Once the controller is interacting with the screw, the screw will be highlighted yellow (refer to chapter 7.4). When the screw has been loosened up, the black cable can be moved upwards to break the connection with the battery (Fig 6.11d).

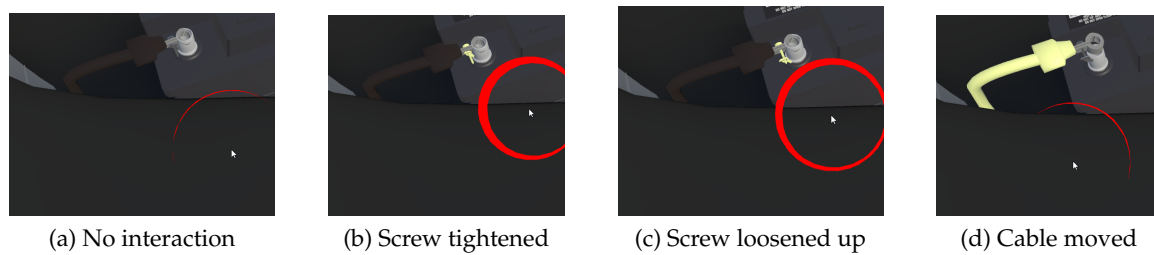


Figure 6.11.: Steps for disconnecting the 12V car battery

6.5.3. Secure the 12V car battery with a padlock

Once the the earth lead has been disconnected from the battery's negative terminal, it should not accidentally be re-attached. Accidental re-attachment, refers here also to the situation where another employee would re-connect the cable, without realizing that someone is currently working on the car. To prevent this, a padlock is placed on the ring at the top of the cable connector (Fig 6.12).

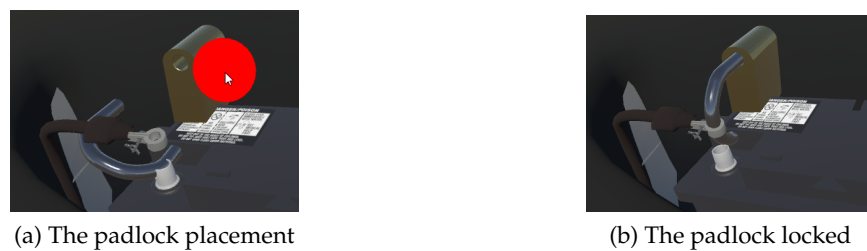


Figure 6.12.: Securing the 12V battery with the padlock

6.6. Determine absence of voltage inside the electric car

A Duspol device is used to measure voltage in the electric cars. There are three models of this device: analog, digital and expert (Fig 6.13a). In this VR tutorial, the Duspol expert device was implemented. The Duspol manual [4] introduces all the relevant information on using these devices, which is summarized in the next chapter.

6.6.1. Model the voltage measuring device

Duspol devices consist of two separate parts: a positive end and a negative end, connected with a cable. The voltage is measured as a difference of potentials between the positive and the negative end of the Duspol device. The measured voltage value is indicated by a set of diod lights attached to the positive end of the Duspol device. To measure the voltage value, the user places the probe at the top of positive end of a Duspol device on the positive potential point of the object he wants to measure and the negative probe on the ground or the negative potential point. In this case, the user gets the accurate reading of the voltage difference for the target object's points. If any of the probes of the Duspol device are not placed next to the voltage potential point, they have a potential value of 0 and act as a ground point.

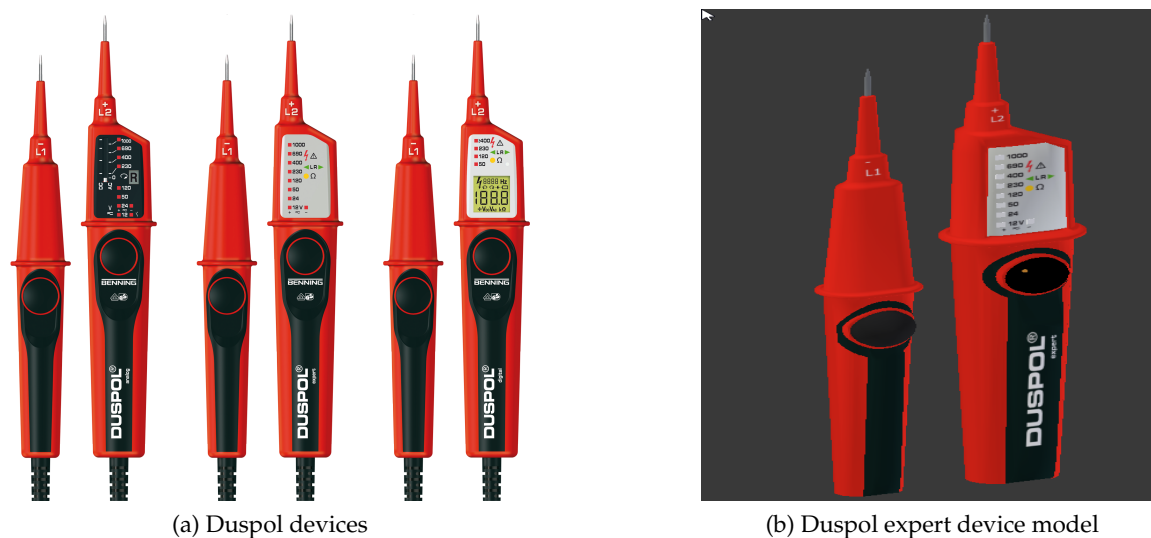


Figure 6.13.: Duspol devices and the expert device model

Expert Duspol devices (Fig 6.13b) measure voltage thresholds. They can detect voltage levels of 24V, 50V, 120V, 230V, 400V and AC 690V / DC 750V. A higher voltage than 1,000 V could damage the Duspol device. The Duspol device can also measure a lower voltage value of 12V in case both buttons on it are pressed. Furthermore, the Duspol device will

also indicate if the measured voltage has a positive flow, i.e. the positive probe of the Duspol device is measuring the voltage potential higher than the negative probe, in which case the plus diode lights up. If the flow is negative, the minus diode lights up. However, the user can use the Duspol device to measure an alternating current, in which case both plus and minus diodes will light up during the measurement.

6.6.2. Measure the voltage inside the VR course

In the VR course, the user is able to grab both ends of the Duspol device and move them around. The probes on the top of the positive and the negative end of the Duspol device react when they are placed in the colliding area of the voltage potential value. The object's potential points are child components of this object, named either 'positive' or 'negative' depending on their potential value. These child components contain only a "Box Collider" and a script "Voltage Component" with specified potential value.

The scripts "Duspol_minus" and "Duspol_plus" are implementing all the functionalities of the Duspol device. The "Duspol_minus" script is attached to the negative end of the Duspol device and is detected when this end is in touch with a voltage potential point. It then stores the voltage value as well as the point it is interacting with and informs the positive end. The "Duspol_plus" script is attached to the positive end of the Duspol device. Same as the negative end, it detects contact with voltage potential points. Furthermore, it is responsible to measure the current voltage of the Duspol device and turn relevant diodes on and off to display the measured value.

6.6.3. Example virtual objects for the voltage measurement

The Duspol device is designed to detect and measure both a direct current (DC) and an alternating current (AC), therefore example objects for both current types are present in this VR course.

The electric battery (Fig 6.14a) is designed as an example device for DC. If the user places the positive end of the Duspol device on the battery's positive potential end, the device will measure the battery potential. An electric battery has a potential of only 1.2V. The Duspol device is able to detect only voltage starting from the threshold of 12V. Therefore, if the user tries to measure the battery voltage, he will only see that the light for positive current has been activated but no threshold has been reached. If the user tries to measure with the Duspol's negative point, he will get the same value but for the current's negative direction. The car battery (Fig 6.14b) also represents an example of a DC device with a voltage level of 12V.

The electric socket (Fig 6.14c) is an example of an AC device. Any hole inside the electric socket has the same potential value of 230V. If only one end of the Duspol device is plugged in, the current value is 230V and it is displayed as a direct current value. Only if both ends of the Duspol device are plugged into the socket, the device measures 230V of alternating current.

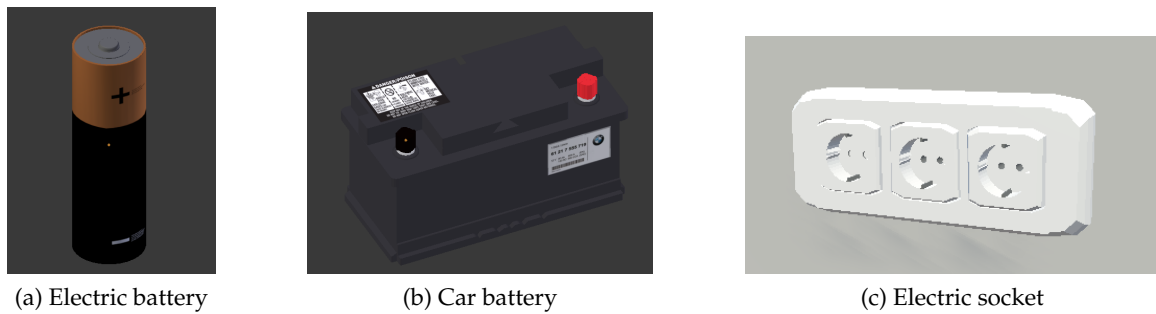


Figure 6.14.: Examples of electric devices

6.6.4. The high voltage points inside the electric car

The easiest way to gain access to the high voltage points in the BMW i3 is through the high voltage cables connected to the vehicle's engine. The high voltage cables are in the back trunk of the car. The employee has to remove the protection cover in the back car trunk (Fig 6.15a) and open the high voltage connector. Then, he is able to access the high voltage points for the measurement. The "High Voltage Component" manual [9] shows how to open up a high voltage connector (Fig 6.15b).

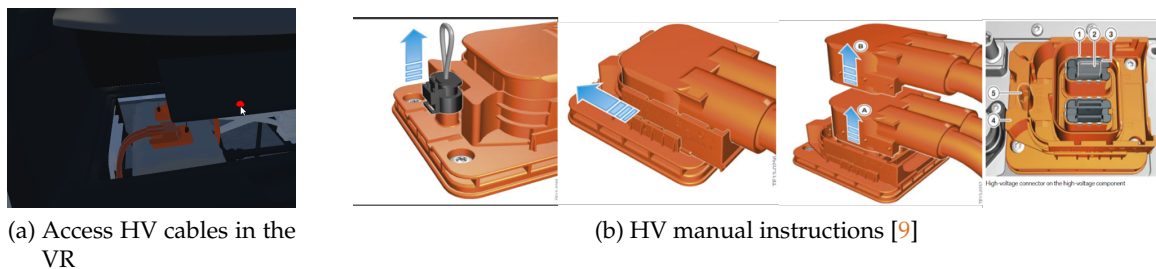


Figure 6.15.: The high voltage cables in the BMW i3

The steps from the manual are implemented inside the VR course. First, the user has to remove the connection bridge, a safety measure against accessing high voltage wiring. The connection bridge is the plastic black cover blocking the mechanical lock. The connection bridge in the VR course is an 'Attachable Throwable' (chapter 7.1.2) and can be picked up and removed by the user (Fig 6.16a).

Second, when the connection bridge is removed, the user is able to slide the mechanical lock to the far right (Fig 6.16b). This, in turn, frees the connection cable placed above the mechanical lock. The third and final step is to move the connection cable from its original position upwards (Fig 6.16c). This reveals the black wiring objects hidden by that cable.

The wiring objects are highly dangerous and, when the high voltage system of BMW i3 is not disconnected measure 400V of DC. If the BMW i3 car is disconnected properly, the

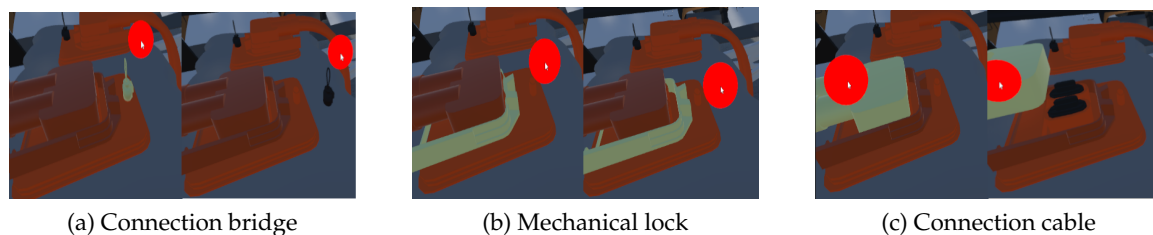


Figure 6.16.: Accessing HV points in the BMW i3

user is able to measure that the voltage level of this component is 0V. The discharging process is not instantaneous but rather a linear function of time. The user has to wait for a short period of time (in the VR course this is 1 minute of waiting time while in real life it would be 5 minutes) before the voltage will fall from 400V to 0V after the high voltage system in BMW i3 has been disconnected. If the user measures the voltage during this discharging period, he is able to see the voltage drop.

6.7. Mark the electric vehicle as safe to work with

The employee is allowed to mark the electric vehicle as safe to work with only after he has checked that the high voltage components indeed have voltage value of 0V and secured dangerous points against re-connecting. The high voltage components in the BMW i3 count as checked for the voltage absence only after they have been measured by the Duspol device and the resulting value has been 0V. Dangerous points, the emergency disconnect switch and the 12V car battery count as secured against re-connecting only if a padlock has been placed on them.

The user places the "Do not switch off! It is worked on" sign (Fig 6.17a) on a rear-view mirror of the car when he wants to mark the vehicle as safe to work on. This sign indicates to other employees that they should not temper with the electrical system in the vehicle and that, at the moment, the electric system in this car has been switched off.

In the VR course, the user has to find this sign at one of the working tables. When he is sure that all the necessary actions have been performed, he marks the car as safe by placing this sign on the rear-view mirror (Fig 6.17b). The "Do not switch off! It is worked on" sign object in the VR course is an 'Attachable throwable', which means it will snap to the place when near the mirror. Once the user drops the sign in its place, the action for finishing the tutorial is triggered and the user crosses to the final scene.

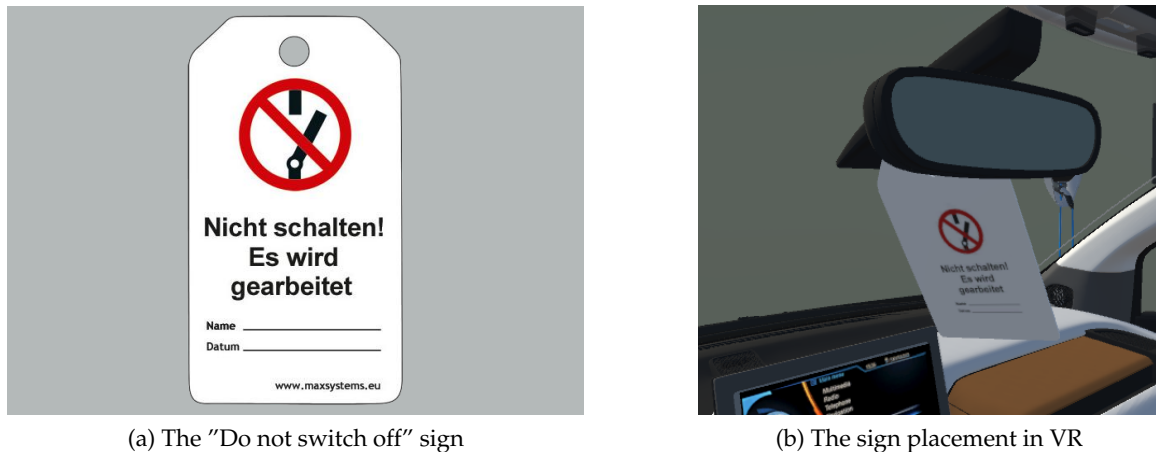


Figure 6.17.: The vehicle is safe to work on sign

6.8. Game logic and user performance grading

In the VR tutorial, the user is guided in which way to accurately disconnect the electric vehicle. As mentioned before, the vehicle is turned on in the beginning of the tutorial and the high voltage system is active. The high voltage system in the BMW i3 produces 400V DC, which is life-threatening in case of direct contact. Therefore, it is crucial to accurately follow the safety steps for disconnecting the vehicle in order to avoid any hazardous situations.

The user gets the list of steps to perform when disconnecting the vehicle on the check list screen (refer to chapter [section 6.2](#)). However, he is not forced to follow the order of these steps and can interact with the vehicle in any way he chooses. His actions are tracked by the game and he is graded according to the safety of the steps he performed.

If the user gets in direct contact with a high voltage component with a potential value bigger than 15V of direct current at the time, the user automatically fails the tutorial. This situation would cause the employee to get electrocuted in real life and, therefore, is punished rigorously. He gets the same consequence if he marks the vehicle as safe to work with before he insured that the vehicle is indeed disconnected, with all the necessary steps. With inadequate checking, he puts himself and his colleagues at the work place in danger.

Actions that would not put the employee or his coworkers in immediate danger, but are still discouraged because they could lead to smaller injures or uncomfortable situations, are graded with negative points. The user will still be able to pass the tutorial even with negative points, but they will influence his final score.

The table bellow lists the steps and their grading:

6. Working with the vehicle

Steps for switching off HV on the electric vehicle		
Step	Description	Depends on
1	switch the car off	-
2	activate emergency disconnect switch	if 1. STEP not done -10 PTS
3	secure the switch with the padlock	if 2. STEP not done CAN'T DO
4	disconnect 12V car battery	if 1. STEP not done -10 PTS if 2. STEP not done -10 PTS
5	secure 12V car battery with the padlock	if 4. STEP not done CAN'T DO
6	determine absence of voltage on the car	if 1., 2. and 4. STEP not done FAIL
7	mark the car as safe to work with	if 3., 5. and 6. STEP not done FAIL

7. Reusable Scripts

During the implementation of the “High Voltage Electric Vehicle Security” VR tutorial, an attention was dedicated to encapsulating the reusable virtual objects’ features and functionality. This way they can be implemented as part of any future educational tutorials. The scripts are written in C# for Unity applications as an extension to SteamVR. These scripts are summarized in this chapter.

7.1. Re-attachable virtual object

7.1.1. “Throwable” object from the SteamVR

In SteamVR, a “Throwable” is a virtual object with a rigid body influenced by gravity. The object can be picked up with the press of a trigger button on the controller and moved around with the virtual hand. When the trigger button is released, the object is considered dropped or thrown, depending on the motion of the virtual hand at the time. Its trajectory is calculated by the physics projectile motion.

7.1.2. “AttachableThrowable” script

“AttachableThrowable” is an extension to the “Throwable” script. In addition to the previously described behavior, the object can be attached to the specified position in the room. This position is defined by a parent object which contains an “AttachBack” script. If the “AttachableThrowable” object is attached to its parent, the position of the object in that coordinate system is updated in each frame, keeping it attached even when the parent object is moved in the virtual world.

7.1.3. “Padlock” script

A “Padlock” script is an extension to the “Attachable throwable” script. Aside from its parent to whom the “Padlock” can be attached, it can also be attached to the target object in order to lock it. Target objects can have a “conditionalLock” tag. The padlock will always lock the target object if it is dropped in its collider area and the object is not a “conditionalLock”. In case the object is a “conditionalLock”, it is an object of the type “Slider” (chapter 7.2.1) and it has to be unlocked and its parameter “canBeLocked” has to be set to true in order for a locking mechanism to be activated.

The "Padlock" script should be assigned to the padlock Blender model (Fig 7.1), with opening and closing animations. The script automatically calls the opening padlock animation each time the padlock is taken by the controller, and the closing animation when the padlock is attached back to the parent or target object it locks.

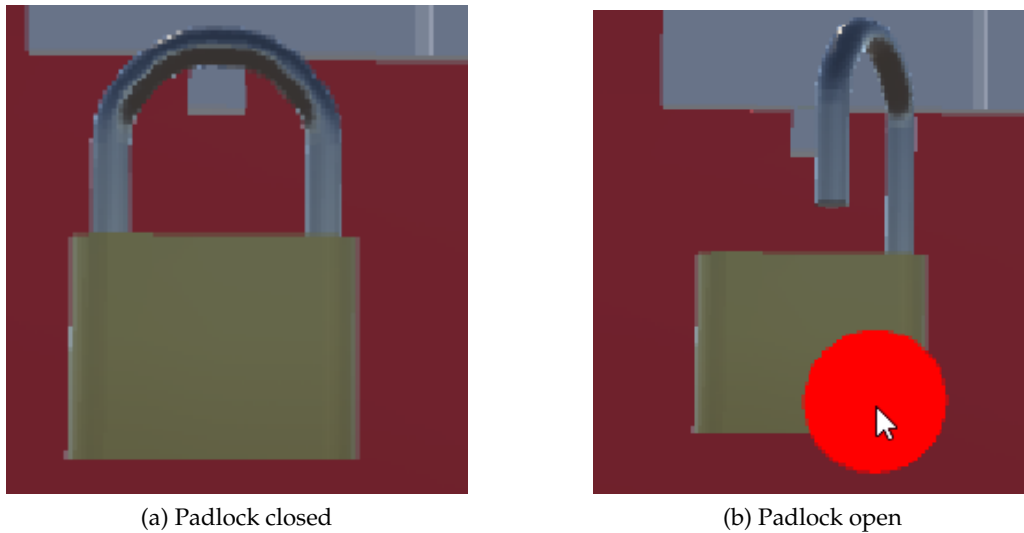


Figure 7.1.: Padlock in closed and open state

7.1.4. "AttachBack" script

An "AttachBack" virtual object presents an attachment location for "AttachableThrowable" (or "Padlock") objects with the specified name. If the object with the matching name, specified by public parameter 'Object Name' (Fig 7.2), enters its collider area, it automatically snaps to the attachment position. In case it is dropped by the virtual hand in this state, it becomes attached to the "AttachBack" object. The "AttachBack" script allows the attachment of only one object at the time and it is responsible for storing information of the attachment position. Attachment position can be automatically calculated from the starting position of the "AttachableThrowable" object if it starts as attached in the moment of the scene load and 'Automatic Loc Rot Setting' is enabled. The developer can also specify an attachment position manually in the script's public parameters by disabling 'Automatic Loc Rot Setting'.

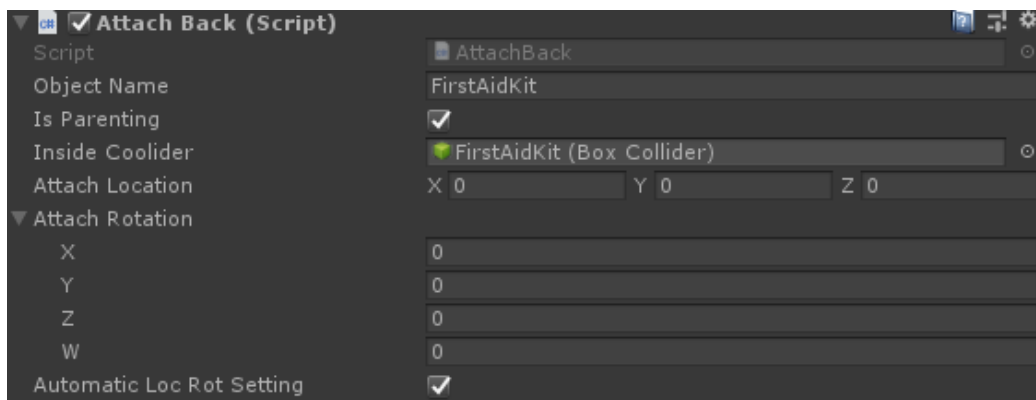


Figure 7.2.: "AttachBack" script's public parameters

7.1.5. Snapping functionality

It is complicated for the user to register at which point the "AttachableThrowable" object is in the collider area with its possible "AttachBack" parent object. Therefore, the snapping functionality has been implemented as an addition to the "AttachableThrowable" objects. It enables objects to automatically snap into the right attachment place when they are in the parent's collider area. This helps the user to visually see that an object is in the collider area and can now be dropped to be attached to this place. If the user decides not to drop the object, he can just drag it out again and the object will snap back to his hand in the previous position the moment he is away from the parent's collider area. The difference between the collider area that registers the object appearance is about 5% smaller than the collider area for registering that the object has been taken away. This is done for the application stability so the object don't keep jumping from the hand and back when on the collider border line.

7.2. Sliding virtual objects

A slider here refers to a real world object that contains one smaller part which can move along specified line in both directions. It can slide between two border points on this direction line and take any position in between. Some positions, most often border points, can be trigger points.

7.2.1. "Slider" script

A "Slider" virtual object is an interactable VR component which mimics the behavior of a slider and can be dragged along a defined line with the virtual hand. The 'Slider' public

parameter inside the script expects reference to the moving part of the object. The developer can specify the direction line by selecting one or more direction axes (Fig 7.3). The axes along which the slider will be moved are its local coordinate system axes. One unit of movement is statically defined as 0.001 mm per frame. The "Distance" parameter specifies the maximum offset the slider can take from its original position in the movement direction.

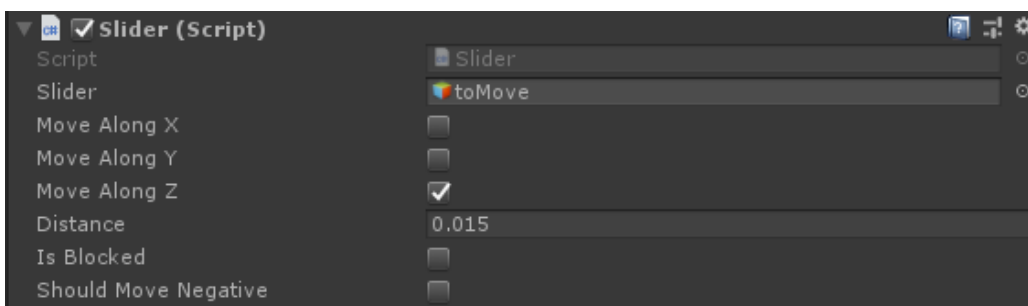


Figure 7.3.: "Slider" script's public parameters

Normally, the slider can be moved in the positive direction along its local coordinate system. With selecting 'Should Move Negative' in the public parameters, the slider movement is switched to negative direction instead. The trigger point of the slider is the maximum distance from its original position, no matter the decided direction. In this VR course, the trigger point is used as a signal that this slider can be locked with the "Padlock" object or as a trigger for unblocking another object.

If the user has grabbed the slider, meaning that he has pressed and is holding trigger button on the controllers while in the slider's collider area the slider moves together with the controller. If the user moves the controller upwards the slider is dragged along the positive direction along the specified axes. If at any point the controllers leave one of the slider's collider areas the slider is automatically dropped. If the slider reaches its border positions, further movement in that direction is impossible.

7.2.2. "Blockable" script

The "Slider" object can be blocked from moving by enabling a 'Is Blocked' public parameter. By setting its value, the developer is able to specify if a slider is blocked or not at the beginning of the game. This parameter is likely to change its value by user interaction with opening or closing another virtual object (refer to a cable and a screw example 6.5.2). For this reason, a simple "Blockable" script (Fig 7.4) has been implemented which allows to block or unblock a specified slider object as an additional consequence to the opening and closing animation of the current object.

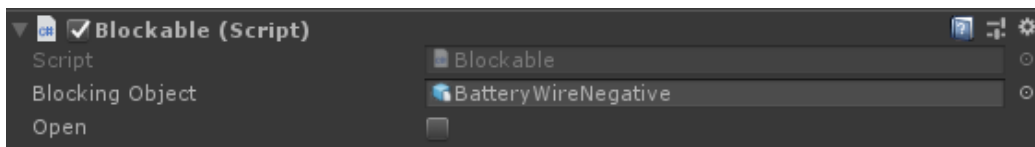


Figure 7.4.: "Blockable" script's public parameters

7.3. Hidden objects in the VR

In the virtual reality application, each object has its own size and space defined by the collider. Virtual objects appear solid, but the user is able to reach through them, either with head mounted display or with motion controllers, because of the lack of a physical barrier. If the object in question contains another virtual object hidden inside, the user could interact with it unknowingly. To prevent this, all interactable objects which are hidden by another virtual object are disabled. This way, the user is able to interact only with the outside objects as intended. Only after opening up the outer virtual object, the interactable virtual objects hidden inside appear and the user gains access to them.

The reusable element is the "DeactivateInside" script. The developer is able to set up a list of objects that should be enabled or disabled in the same time. The disabling function has an effect on the object only if it is currently attached to any parent. If the object is not attached to another virtual object, it also cannot be hidden by this object. Example is given in Fig 7.5. The padlock box occludes padlocks and they are disabled until the user opens the padlock box door.

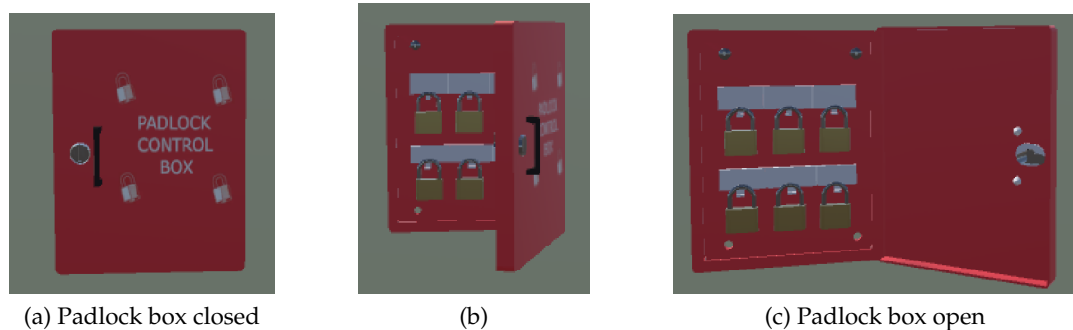


Figure 7.5.: Padlock box and the containing padlocks

7.4. Highlight the interacted virtual object

When the user touches a virtual object with the controller, the controller will glow yellow. This indicates that the user is able to use the controller now to interact with the virtual

object. This information is very subtle and sometimes not noticed by first time users.

Secondly, the fact that the controller is interacting with something within the virtual world is not very helpful to indicate which is this object. In the case of a small or near placed virtual objects, it can become very inconvenient to make a distinction between multiple virtual objects. The highlighting option for the virtual object means that this object will become yellow itself when it is interacting with the controller, so the user has a clear indication what object he is touching at the moment. The example bellow (Fig 7.6) demonstrates how different elements of virtual object glow yellow depending on which one is currently touched by the virtual hand (represented by the cursor in the provided pictures).

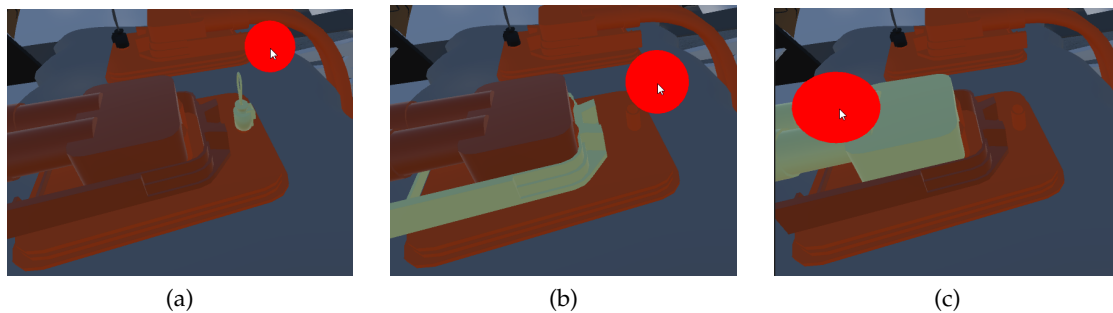


Figure 7.6.: Highlight currently interacted object part

7.5. Virtual objects from the exhibition table

In the VR intro room (Chapter 4), the user is introduced to the exhibition table where every virtual object can be picked up from its original position with the trigger button. The moment the object is picked up, a more detailed object description appears on the plane on the object’s right side. If the user drops the object, it will automatically jump back to its original position on the table. This functionality is implemented in the “PickupObject” script (Fig 7.7).

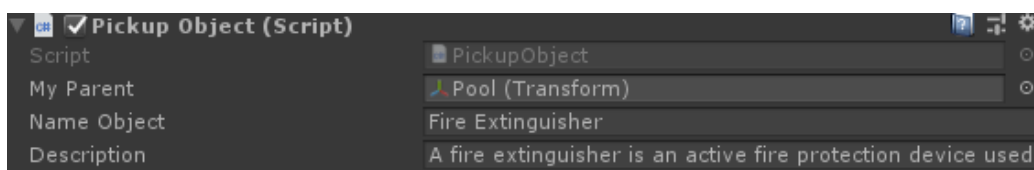


Figure 7.7.: “PickUpObject” script

In the ‘Name Object’ and the ‘Description’ public parameters, the developer can specify all the necessary information about this virtual object. The plane which shows the object

description should be already existent in the scene with the name 'ObjectDetailExplanation'. It should be world space canvas consisting of two "Text" components: title and information. They are filled respectively with the two mentioned "PickupObject" public parameters every time a new object is picked up (Fig 7.8).

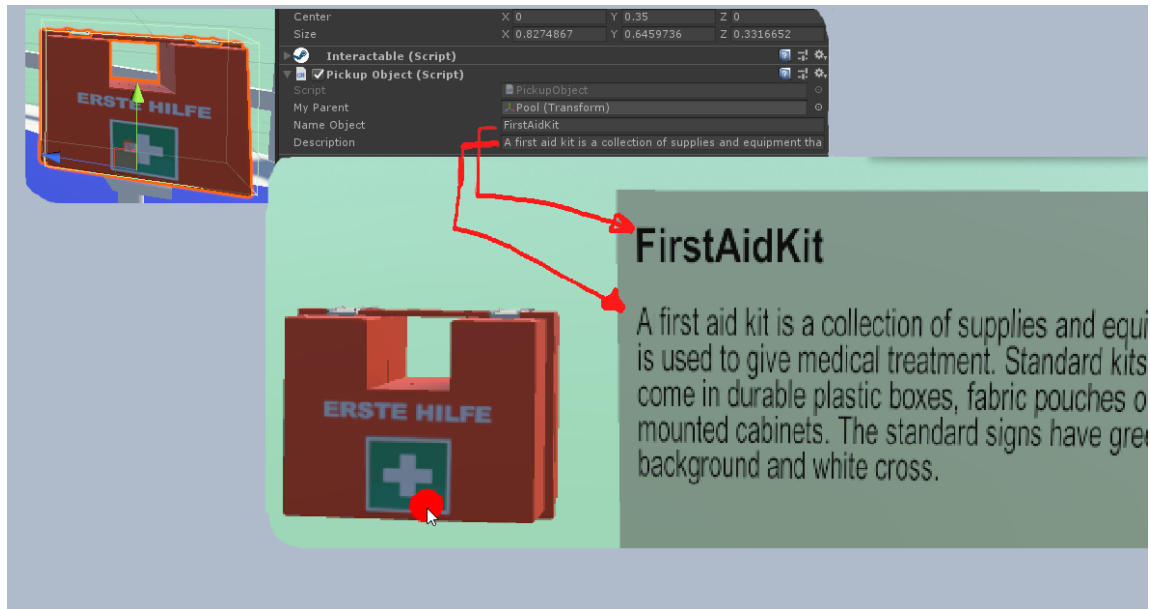


Figure 7.8.: Minimized "PickUpObject" script with an example

Part III.

User testing and feedback

8. User testing preparation

After the virtual reality tutorial was implemented, the user study was conducted in order to test the application. The testing was organized internally, only with the company employees. The selected candidates were required to complete the virtual tutorial and afterwards fill out a related questionnaire and a quiz. The questionnaire is focused on the previous knowledge and similar experiences, while the quiz tests the understanding of the virtual tutorial content. Finally, for statistic purposes, additional data is obtained during the user study from the user activity application log.

8.1. Testing candidates selection

The test candidates for the user study have been selected from the company's employees. They are familiar with working in the industrial setup, but it was not relevant for the candidates to be full-time employees. Therefore, working students have also been eligible for this user study.

The virtual tutorial has been built to consider different levels of topic and technology familiarity from the participants. The selected candidates should fulfill the same amount of diversity and have been chosen according to this criteria. Within the diversity criteria, two main aspects are in the primary focus.

8.1.1. Familiarity with the technology

First, the goal of this virtual tutorial was to test the advantages and disadvantages of using VR for an industrial education. Coming from different backgrounds, the users might have a vast or a very limited amount of the previous experiences with the VR technology. Nevertheless, it is necessary that the VR application is intuitive and easy to navigate through, both for the users who have used VR often (or own a VR headset for gaming or work) as well as for the people who are experiencing VR technology for the first time. In order to test this, the user study candidate's pool would have to contain different VR experience levels.

The users should be able to easily understand instructions and perform given tasks at their own pace through the application, but they should also learn and have fun in the process. To make the learning experience more entertaining and intuitive, the VR tutorial is designed to animate users and contains gamification elements. The gamification is explained by Cheong, Filippou and Cheong [3] as a concept that "makes use of elements

from games, which are well known for motivating and engaging players for lengthy periods, and apply them to non-game contexts in order to recreate the same level of motivation and engagement for other purposes." The gamification aspect could provide a different experience both for the users who are familiar with this concept or games in general and the ones who do not spend much time in this branch of entertainment. In the literature review from 2014 [12], it is seen that the gamification concepts have not been used only for traditional education, but also "carried out within companies for the purposes of in-service training." This virtual tutorial is testing the same advantage in combination with the VR technology.

8.1.2. Familiarity with the tutorial content

Second, this virtual tutorial is an implementation of the "High Voltage Electric Vehicle Security" course, an educational course on how to safely disconnect high voltage components in the electric vehicles. Additionally, the course also teaches the necessary security measures inside the work space.

The test candidates who worked before with high voltage or the electric vehicles would be expected to have better understanding of the course content compared to someone who is new to this topic. The BMW i3 is an electric car model in this virtual tutorial, giving additional advantage to the users who have driven or opened this car before. Furthermore, if the test candidate has taken the current version of the "High Voltage Electric Vehicle Security" course, he would be able to provide an interesting comparison between his experiences from this course and the VR tutorial.

The employees in the different company departments were likely introduced with some aspects of security measures. These security measures could be the same as the ones which are the necessary part of this virtual tutorial, chapter 5.3, or it could be its subset. Depending on the subset of these security measures that the employee has been familiarized with before, he might react differently to the content provided in the VR tutorial.

The mentioned aspects are important to be defined and considered during the user study and the result processing afterwards. Independent of only previous knowledge of the candidates, the virtual reality tutorial has to be fun, educational and realistically reproduce the real life situation.

8.1.3. Test groups

Based on the two main aspects from the previous chapters, four basic groups of candidates are defined. The goal was to acquire people belonging to each group defined in the table below. The user testing was organized in the period of three consecutive work days and the total number of participants was fourteen.

Four basic test groups for the user study candidates			
	Virtual Reality Experience	Electric Vehicle Experience	Number of Users
Group 1	✓	✗	0
Group 2	✓	✓	3
Group 3	✗	✓	3
Group 4	✗	✗	8
Total number of user: 14			

8.2. Questionnaire for the user study participants

The user study participants are selected from the four different target groups defined in the previous chapter. Membership to these target groups is expected to influence the application experience and the obtained results from the user study. Each participant is asked to fill in a questionnaire about their background knowledge, allowing to evaluate a possible correlation between this data and the results from their participation in the study. Focus of the questionnaire is experience with the virtual reality technology, gamification, and this course's content.

The questionnaire is created in Survey Monkey with ten questions. First, the user has to provide his participant ID (Fig 8.1). The ID is generated automatically from the user's order in the test study. Each application run will check from how many candidates the data has been collected and calculate the participant's ID as this number increased by one. The user gets the ID from the application once the tutorial has been completed.

TM-VR-Schulungen evaluation testing

⊕ PAGE TITLE

* 1. What is your course participant ID?

Figure 8.1.: Question 1 from the "TM-VR-Schulungen" questionnaire

The next three questions (Fig 8.2 and Fig 8.3) focus on the user's familiarity with virtual reality, gamification and games. Afterwards, the user is asked if he has completed the current version of the "High Voltage Electric Vehicle Security" course and, finally, what is his experience with working on the electric vehicles and the high voltage component systems (Fig 8.4).

8. User testing preparation

* 2. Do you have previous VR experience?

- I am a developer in VR
- I am regular playing games or testing software in VR
- I have occasionally played with VR headset
- I have once or twice tried VR headset
- I have never tried VR before

Figure 8.2.: Questions 2 from the "TM-VR-Schulungen" questionnaire

* 3. Do you have game experience?

- I have done game development
- I am passionate gamer (computer)
- I regularly play different computer games in my free time
- I sometimes play computer games
- I have little interest in computer games

* 4. Do you have gamification experience?

- I have developed software with gamification elements
- I have tested software with gamification elements
- I have only tried software with gamification elements
- I have no idea what gamification is

Figure 8.3.: Questions 3&4 from the "TM-VR-Schulungen" questionnaire

* 5. Have you done current "High-voltage security in vehicles" course by Mersim Ramdedovic?

- Yes
- No

* 6. Have you worked with electric vehicles?

- I am regularly working with the electric vehicle high-voltage components
- I am regularly working with BMW i3 high-voltage components
- I have before shut down high-voltage system on BMW i3
- I have before shut down high-voltage system on any electric vehicle
- I own a BMW i3
- I own an electric vehicle
- I have driven a BMW i3
- I have driven any electric vehicle
- I have never driven any electric vehicle

Figure 8.4.: Questions 5&6 from the "TM-VR-Schulungen" questionnaire

The last four questions (Fig 8.5) focus on the user experience during his participation in the virtual tutorial. He is asked to grade how enjoyable and how complicated the experi-

ence was, how sure he feels that this experience would help him in the real world situations, and finally, he has an open question to provide suggestions for the improvement of the application.

7. Did you have fun doing this VR tutorial? Which part was most interesting?

8. Did you get lost at some point during VR tutorial? Where?

* 9. How well do you feel you would be able to repeat these steps now in real life situation?



10. Any other suggestion you have for this VR tutorial?

Figure 8.5.: Questions 7-10 from the "TM-VR-Schulungen" questionnaire

8.3. Quiz for the user study participants

The quiz is created also in Survey Monkey and has seven questions. The participants are asked to fill in the quiz right after they have completed the questionnaire. It is designed to test the participant's knowledge of the tasks he is required to perform during the virtual tutorial.

The user is also required to fill in his participant ID at the beginning of the quiz (Fig 8.6) so that this data can be uniquely connected to the questionnaire's information and the data log from the application. The user should also answer if he has successfully passed the first part of the virtual tutorial (namely security objects marking task) and the second part (disconnecting the high voltage system on the BMW i3 model).

The image shows a quiz interface with a green header bar containing the text "TM-VR-Schulungen Quizz". Below the header is a button labeled "PAGE TITLE". The quiz consists of three questions:

1. What is your course participant ID?
A text input field is provided for the answer.
2. Did you pass the object marking level?
Two radio button options are shown: "Yes" and "No".
3. Did you pass the VR tutorial?
Two radio button options are shown: "Yes" and "No".

Figure 8.6.: Questions 1-3 from the "TM-VR-Schulungen" quiz

The next two quiz questions test how well the user has learned the information from the security objects marking task. He is presented with a set of images (Fig 8.7) and asked to pick only those which represent the security objects. The user is provided both with the images from online sources and the object models he has encountered in the virtual tutorial.

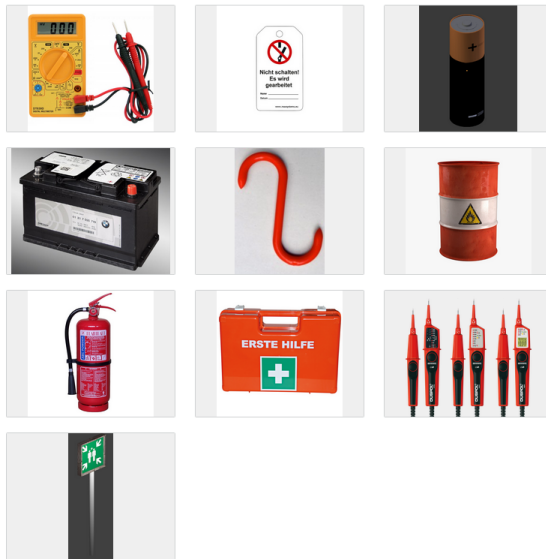
Not all emergency objects are present within the images and some of them appear more than once. The object repetition is in different formats: some are the ones provided in the virtual tutorial, while others differ in shape, size or colour. Examples are: an assembly point and a rescue safety hook.

An assembly point, in the already known format, is presented as a meeting place map positioned on the wall inside the garage room (the fifth picture in question 5). It also appears as an outdoor sign representation of the gathering spot, the format not previously seen in the tutorial (the last picture in question 4). Both pictures are considered to be a correct answer.

A rescue safety hook changes the orientation and the colour within the quiz questions. As a fifth picture in question 4, the rescue safety hook is the smaller and rotated red object compared to the familiar longer, black pool (the third picture in question 5) the user has seen in the VR tutorial.

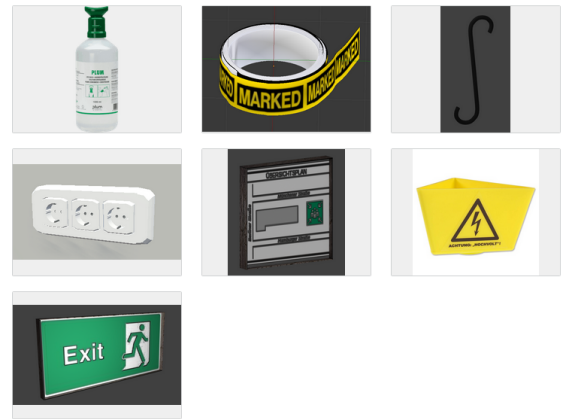
These kind of examples within the quiz test whether the user is able to generalize the information obtained from the virtual tutorial and apply it in new situations.

4. Which picture represents emergency object?



(a) Question 4

5. Which picture represents emergency object?



(b) Question 5

Figure 8.7.: Questions 4&5 from the "TM-VR-Schulungen" quiz

The next question (Fig 8.8) tests the knowledge from the second part of the virtual tutorial. In this part, the user was guided through the set of steps on the instruction screen how to safely disconnect the high voltage components inside the BMW i3. The steps should be completed in the specified order.

In the quiz question, the user is provided with the same list of instruction steps he has seen in the virtual tutorial. However, the order of the steps in this list are randomized. The user is required to order the steps again according to the tasks he had to perform to disconnect the voltage in the electric vehicle. On the left side of each step in the list he can select one number corresponding to the order of this step's execution.

6. Order the accurate set of events.

⋮	<input type="text"/>	Turn off the electric car
⋮	<input type="text"/>	Activate the emergency disconnect switch
⋮	<input type="text"/>	Secure the emergency disconnect switch with the padlock
⋮	<input type="text"/>	Disconnect 12 V car battery
⋮	<input type="text"/>	Secure the 12 V car battery with the padlock
⋮	<input type="text"/>	Mark the electric vehicle safe to work on
⋮	<input type="text"/>	Remove bridge on high-voltage component
⋮	<input type="text"/>	Move mechanical lock on high-voltage component
⋮	<input type="text"/>	Remove cable on high-voltage component
⋮	<input type="text"/>	Measure voltage on high-voltage component
⋮	<input type="text"/>	Losen the screw on 12 v car battery

Figure 8.8.: Question 6 from the "TM-VR-Schulungen" quiz

Finally, the user is tested on the details which are not the part of the explicit tasks within the virtual tutorial. In the VR intro room, the user was offered an opportunity to get familiar with the security objects. On the exhibition table, he was able to see the appearance of every security object but also to get more information about its naming and functionality.

Some of the security objects, like an exit sign, are general knowledge. However, the rescue safety hook is something that the participants might not have encountered before. Therefore, in the last quiz question (Fig 8.9) they will be asked to explain the meaning and functionality of the rescue safety hook. It is an open type question. The evaluation will

grade if the user remembers the usage of this object, while knowing the adequate naming for it will be nice additional information but less relevant.

Object example



7. What is "object example" used for?

Figure 8.9.: Questions 7 from the "TM-VR-Schulungen quiz"

8.4. Automated time and action tracking and data logging

The user is monitored during his participation in the user study. The constant supervision is necessary to insure well being of the participants as well as for the data collection by observing user actions. In addition to manual monitoring, an automated data logging is

implemented in the application. The virtual tutorial application will track the execution time, the set of actions the user performs and its movement in the virtual world. The tracked actions include: interaction with virtual objects, teleportation between the intro room stations, marking or removing the marking from the objects, level transitions, etc.

Data log is stored on the hard drive in the "D:/Testing Data" folder. The new folder will be generated for each user participating in the study and within the folder the data will be logged in separate textual files corresponding to the application levels. The virtual tutorial consists of four levels and four log files will be generated:

- Intro log.txt
- Marking objects.txt
- Disconnect vehicle.txt
- Heaven scene.txt

At the beginning of each level, the application logs the starting time. At the level end, the end time and the total level duration is logged. Each action within the log file is logged together with the time stamp (amount of seconds passed since the start of the level).

The "Intro log.txt" (Fig 8.10) contains the information from the VR intro room. The application will log when the user has transitioned between the intro station, on which controller he has set up the marking toolkit, completion of the marking task on the example barrow object and interaction with the objects from the exhibition table.

```
Started: 4:50:42 PM
Teleported to ToolsPickUp. Timer: 65.7599999999969
Toolkit set up for left hand. Change nmb: 1. Timer: 67.3499999999977
Teleported to MarkingObject. Timer: 70.5999999999993
Object BarrelMat was marked. Nmb: 1. Timer: 72.4300000000002
Object BarrelMat was unmarked. Nmb: 1. Timer: 74.2400000000011
Teleported to ObjectIntro. Timer: 76.6400000000023
Exhibit object EyePump_body_original has been picked up. Timer: 89.1500000000087
Exhibit object EyePump_body_original has been picked up. Timer: 91.1100000000096
Exhibit object EyePump_body_original has been picked up. Timer: 92.9100000000106
Exhibit object EyePump_body_original has been picked up. Timer: 93.9600000000111
Exhibit object EyePump_body_original has been picked up. Timer: 95.2700000000117
Exhibit object EyePump_body_original has been picked up. Timer: 105.860000000017
Object EyePump_body_original was marked. Nmb: 1. Timer: 112.090000000002
Exhibit object EyePump_body_original has been picked up. Timer: 112.150000000002
Exhibit object FirstAidKit_body_original has been picked up. Timer: 125.060000000027
```

Figure 8.10.: "Intro log.txt" example output

The "Marking objects.txt" (Fig 8.11) keeps track of the execution of the marking task in the virtual garage room. It will log the automatically calculated security objects in the garage room, interaction with each of the objects that has been marked or which marking

8.4. Automated time and action tracking and data logging

```
Started: 4:56:34 PM
Marking objects level started.Objects count:
    1.Exits: 1                2.Alarms: 1                3.Meeting place plans: 1
    4.Fire extinguishers: 1   5.First aid objects: 2     6.Security hooks: 1
    Timer: 40.010000000014
Toolkit set up for left hand. Change nmb: 1. Timer: 40.010000000014
Object FirstAidKit_body_original was marked. Nmb: 1. Timer: 51.500000000007
Object FireExtinguisher_body_original was marked. Nmb: 1. Timer: 72.1400000000043
Object SecurityHook_original was marked. Nmb: 1. Timer: 76.890000000006
Object EyePump_body_original was marked. Nmb: 1. Timer: 104.720000000013
Object FireEscape_map_original was marked. Nmb: 1. Timer: 114.790000000016
Object FireEscape_sign_original was marked. Nmb: 1. Timer: 120.970000000018
Object AlarmPlan_paper_original was marked. Nmb: 1. Timer: 121.510000000018
Marking objects level ended.Marked objects count:
    1.Exits: 1\1            2.Alarms: 1\1            3.Meeting place plans: 1\1
    4.Fire extinguishers: 1\1  5.First aid objects: 2\2  6.Security hooks: 1\1
    7.Decoy objects that were marked: () Timer: 163.820000000001
THE USER HAS SUCESSFULLY MARKED OBJECTS! Timer: 163.820000000001
Ended: 4:59:29 PM
Level duration: 163.820000000001
```

Figure 8.11.: "Marking objects.txt" example output

has been removed and the final score of the task performance with detailed explanation for either pass or fail.

The "Disconnect vehicle.txt" (Fig 8.12) logs the user interaction with each element of the BMW i3 vehicle model. It logs, in addition, the interactions with the instruction touch screen. When the user picks up a padlock or locks any of the car elements, these actions become part of the data. Finally, the user's score on level completion will be logged.

```
Started: 4:59:29 PM
Turn TV on Timer: 49.239999999999
Opened Help 1 Timer: 69.719999999994
Door front right opened Timer: 88.2400000000073
Door front left opened Timer: 114.560000000018
BMW start button pressed. Now the car is off Timer: 147.210000000018
BMW start button pressed. Now the car is on Timer: 152.130000000014
BMW start button pressed. Now the car is off Timer: 154.180000000012
Closed Help 1 Timer: 171.099999999998
Opened Help 2 Timer: 175.699999999994
Front trunk opened Timer: 199.829999999973
EDS re-connected. Voltage rise. Timer: 220.169999999969
...
EDS disconnected. Voltage drop. Timer: 281.129999999928
Closed Help 2 Timer: 285.189999999924
Opened Help 3 Timer: 288.769999999921
Padlock picked up Timer: 352.0199999999864
Padlock dropped Timer: 376.1799999999842
Object Emergency disconnect switch has been locked with padlock. Timer: 376.1799999999842
Closed Help 3 Timer: 386.0499999999833
Opened Help 4 Timer: 416.6799999999805
Battery re-connected. Voltage rise. Timer: 499.4699999999729
...|
```

Figure 8.12.: "Disconnect vehicle.txt" example output

The "Heaven scene.txt" is the summary of the user performance during the second part of the tutorial. It is the same text that the user sees in the application.

```
Started: 5:16:42 PM
Player ID: 2 Timer: 0
CONGRATS!YOU HAVE PASSED :) Timer: 0
You have passed the VR high-voltage course. The amount of points you have lost is: 0 points. Timer: 0
Ended: 5:17:04 PM
Level duration: 20.1100000000003
```

Figure 8.13.: "Heaven scene.txt" example output

8.5. Testing days

Each user was given a time slot of half an hour to accomplish the virtual tutorial. The expected duration was originally set to 15-20 minutes per participant. However, it took longer for test candidates to complete the virtual tutorial. The fastest person completed the tutorial in 16 min while the slowest needed 40 min. The average completion time was 26,1 min.

The questionnaire and the quiz were given to participants to fill in right after the testing. The typical time spent on the questionnaire was 20 minutes while the quiz took about 25 minutes per participant.

Each participant was carefully monitored during their time spent in the VR tutorial. About 70% of the user study test candidates had limited previous experience with the VR, and the motion sickness was expected as a possible negative side effect.

The motion sickness effect in VR was defined already in 1992 as a consequence of "a transformed environment causing errors in perception and perceptual-motor control" [16] which increases by longer time spend inside the virtual environment. It causes the user to feel nausea, cold sweating or dizziness, preventing him to stay in the virtual environment. Chardonnet, Mirzaei and Merienne [13] have worked on predicting visually induced motion sickness (VIMS), "the motion sickness induced by viewing visual motion (as stationary observers)", from the body postural sway signals. Keshavarz and Hecht [14] explored the possibility of reducing it with the sound effects, but with the negative outcome.

During this user study, only one participant experienced VIMS. She had to stop the execution of the tutorial at half time and continue after a short break. Since there are three very distinct levels to complete in the application, it is possible to divide the completion of the VR tutorial in multiple steps, with a short break in between. This would lower the possibilities for the motion sickness effect occurring with the users during the educational tutorial.

9. Result analysis

This chapter is the summary of the results obtained from the user study. It contains statistic data collected from the quiz, the questionnaire and the application log. The data is processed and presented with the goal of discovering the potential that a virtual tutorial would have for the industrial training and education.

9.1. The test candidates background

The test candidates for the user study have been selected with the diverse knowledge in both VR technology and electric vehicle high voltage systems, the topic of this specific virtual tutorial.

Considering the familiarity with VR, 30% of the participants are very comfortable with virtual reality hardware and applications (15% are VR application developers). The remaining 70% are equally divided between people who had a chance to use VR occasionally, in their private or professional life, and those who have maybe tried this technology once before. The user study did not have any test candidate to whom this was his first experience in the VR application. The statistics graph can be seen Fig 9.1.

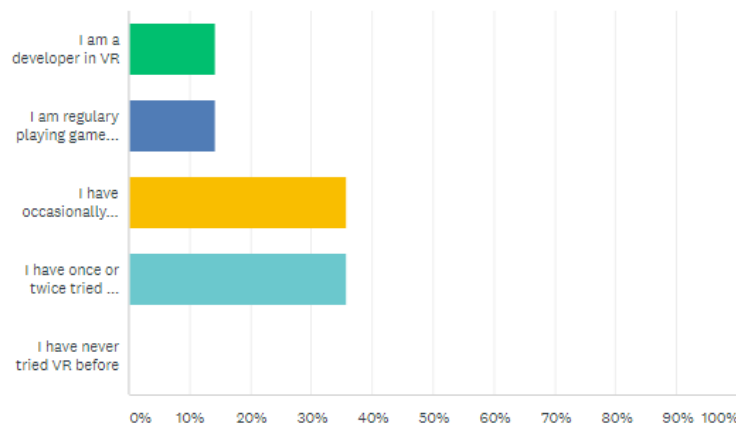


Figure 9.1.: Answers to Question 2 in the "TM-VR-Schulungen" questionnaire

There is almost the same amount of participants in this user study who are familiar with gamification and games as those who have limited knowledge or interest in this area. Each possible answer to the questions 3 and 4 was chosen almost equal amount of time (Fig 9.2).

9. Result analysis

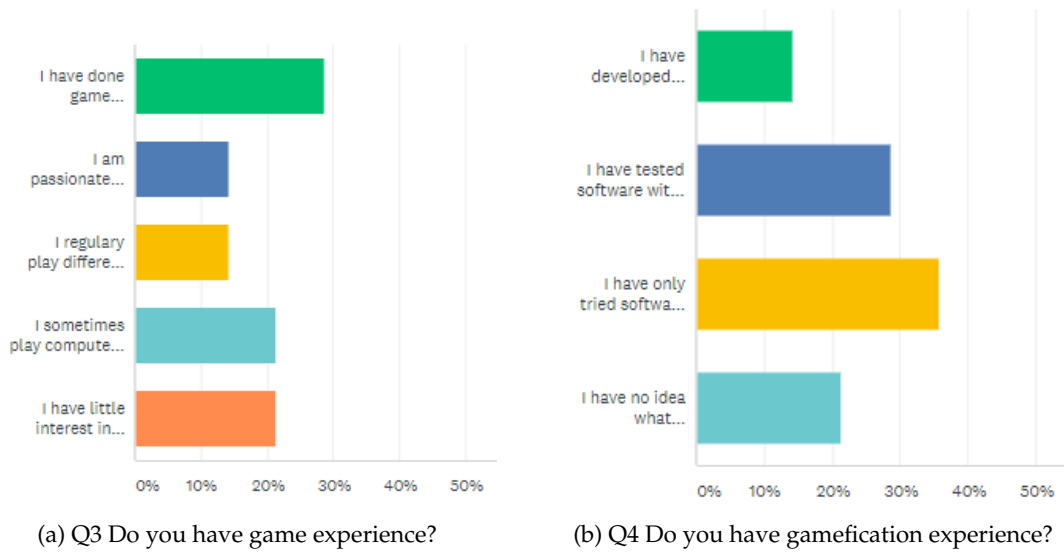


Figure 9.2.: Answers to questions 3 and 4 in the "TM-VR-Schulungen" questionnaire

When it comes to the familiarity with the content of this specific VR tutorial the participants of this user group had rather limited previous knowledge. The current "High Voltage Electric Vehicle Security" course was unfortunately not done by anyone who participated in this user study. The only familiarity with the electric vehicles for most participants was reflected in the fact that they have driven a BMW i3 before, but even this was only 36% of the user study participants. The rest had no familiarity with either high voltage systems in the electric vehicles or the BMW i3 itself (Fig 9.3).

▼ I am regulary working with the electric vehicle high-voltage components	0.00%
▼ I am regulary working with BMW i3 high-voltage components	0.00%
▼ I have before shut down high-voltage system on BMW i3	0.00%
▼ I have before shut down high-voltage system on any electric vehicle	0.00%
▼ I own a BMW i3	0.00%
▼ I own an electric vehicle	7.14%
▼ I have driven a BMW i3	35.71%
▼ I have driven any electric vehicle	0.00%
▼ I have never driven any electric vehicle	57.14%

Figure 9.3.: Answers to question 6 in the "TM-VR-Schulungen" questionnaire

9.2. Virtual tutorial user experience

The user study's participants had two optional questions regarding their experience inside the virtual reality tutorial. The first question focuses on how enjoyable the experience was and the second on whether they felt confused at some point during the tutorial.

The question "Did you get lost at some point during VR tutorial? Where?" revealed two confusing points for the users in the tutorial. The first point was related to not being able to find the padlocks inside the padlock control box when they needed them for the tasks. Even the users who had seen the padlock control box earlier in the tutorial during the marking task, were not able to remember it later when they needed to acquire the padlocks. None of the users felt comfortable exploring the room on their own until they found the solution to this problem, but rather that they needed more comfortable and detailed guidance.

The second confusion point for the users was that the instruction screen in the virtual tutorial is a touch screen. Only two users had the idea that the instruction screen could be interacted with. However, even they could not tell at which point they were close enough to the screen with the controllers so that they expand or minimize the instructions. The perception of the distance to certain virtual objects, like the instruction screen, was a recurring problem. This aspect could be improved by the right hardware selection (refer back to chapter 3.2.1).

The optional question "Did you have fun doing this VR tutorial? Which part was most interesting?" was skipped by just one user, while it received positive feedback from the rest. The users mostly enjoyed the second part of the tutorial when they had a chance to work with the electric vehicle. The couple of interesting answers can be seen on the Fig 9.4 bellow.

- playing around with high voltage on an electrical vehicle and really "touching" the stuff
- The last part was fun because of the gamification.
- yes because it felt very realistic. car with moving parts

Figure 9.4.: Selected answers to question 7 in the "TM-VR-Schulungen" questionnaire

As seen in the selected answer examples, the participants enjoyed the tutorial because they were faced with competitive gamification tasks which made it more interesting and compelling to perform the tasks correctly. It is even more relevant to point out that they found the experience positive because of the realistic feeling when working with the vehicle. Which brings us to the next question: "How well do you feel you would be able to repeat these steps now in real life situation?" The participants felt fairly confident that

they could perform the same task again in the real life situation after passing through this virtual tutorial. On the scale from 1 to 10, the 60% of participants gave the confidence grade of 8, with the rest having gaussian function distribution around this point (Fig 9.5).

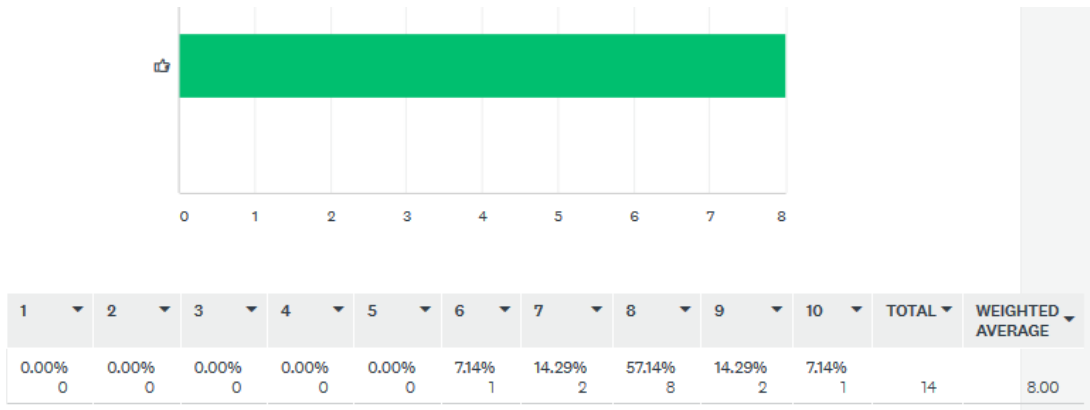


Figure 9.5.: Answers to question 9 in the "TM-VR-Schulungen" questionnaire

9.3. Quiz results

As seen from the answers to question 9 from the "TM-VR-Schulungen" questionnaire, the user study participants felt very confident that they can reproduce the same tasks from the virtual reality tutorial in the real life. This claim has been put to the test by presenting them with the set of questions in "TM-VR-Schulungen" quiz they had to answer after completing the tutorial.

The users were not informed that they are tested on their knowledge of the content of the VR tutorial. There was an email notification about the questionnaire and the quiz which are provided after the tutorial but the topic was not clarified. The results presented are not the product of people preparing for the test but rather opposite.

Disregarding the time necessary to fill out the "TM-VR-Schulungen" questionnaire, there has not been any delay between the completion of the virtual tutorial and the participation in the quiz. Every participant in the user study has completed the quiz in less than 24h after taking the virtual tutorial, with 80% of them completing it within the next two hours. Therefore, it has to be taken into consideration that the performance results from the quiz show only short term effects and memorability of the content.

The first two questions in the quiz are about the success rate of passing the virtual tutorial. The first part of the tutorial, the marking security measures task, had a 70% success rate, while the part of the tutorial where the users had to disconnect the electric vehicle had 100% success rate (Fig 9.6).

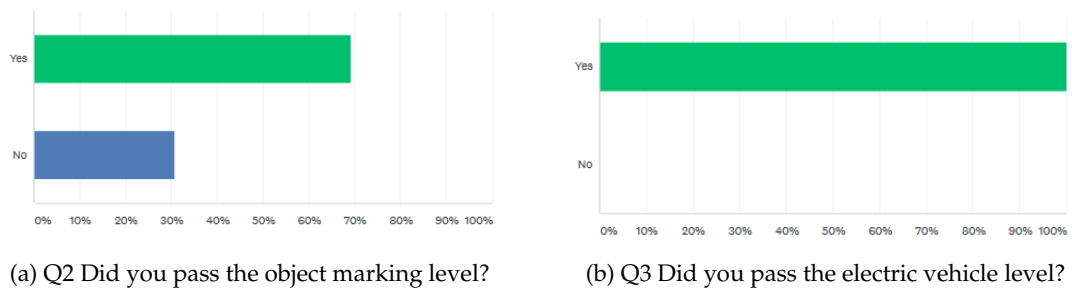


Figure 9.6.: Success rate of the VR tutorial levels

In order to test the user's performance related to the information they have learned from the object marking part of the tutorial, they were presented with 17 example images. Eight out of these 17 images represent the images of the security measures that the user should mark. The rest are decoys of other objects the user has encountered during the tutorial.

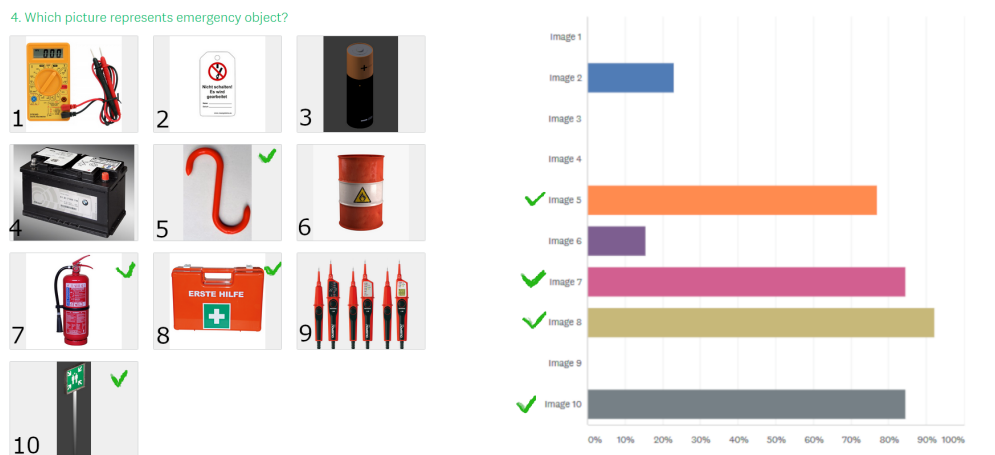


Figure 9.7.: Answers to question 4 in the "TM-VR-Schulungen" quiz

The security objects that should have been selected by the user are marked with the green check mark both on the images and on the answer graphs. We can see that the security objects that appear in the tutorial have been marked with an accuracy of over 90%. The security objects which did not appear in the tutorial directly but are example images of another form from online sources have been marked with an accuracy over 83%. This shows that the users are able to generalize the information from the course and apply it to the new objects as well.

Only between 10% and 20% of the participants had the tendency to mark the objects they have seen or used in the virtual reality tutorial even though they were not part of the security objects.

9. Result analysis

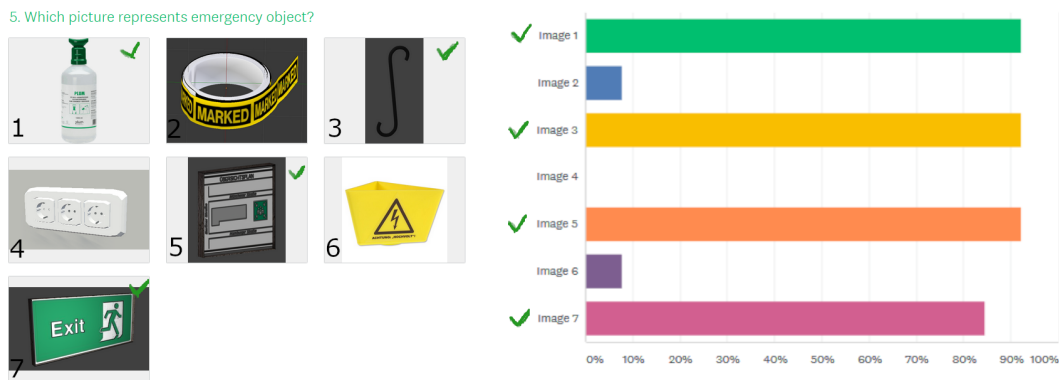


Figure 9.8.: Answers to question 5 in the "TM-VR-Schulungen" quiz

The graph below (Fig 9.9) illustrates the users' answers to the previous questions in regards to the information whether they had passed the tutorial. The green points represent the users that passed the marking tutorial (in 0,0 we have 5 passes) and the red ones those that failed. 'Overmarked' is how many objects were marked that should not have been and 'Undermarked' how many were forgotten. No visible correlation can be established.

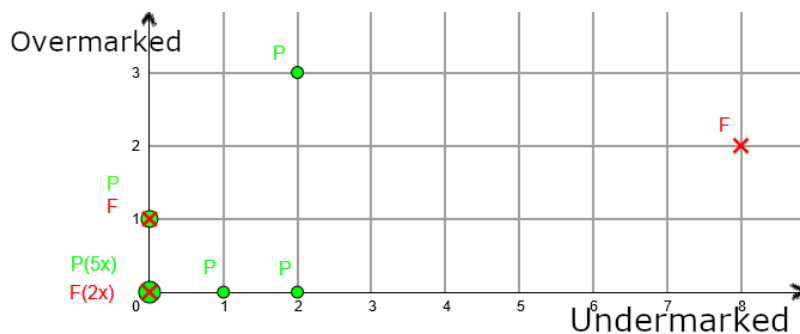


Figure 9.9.: Answers to question 6 in the "TM-VR-Schulungen" quiz

Additionally, the users were asked to explain the usage of the rescue safety hook. Out of the 12 given answers to this question, 8 participants managed to answer the question correctly. This shows that the additional information in the tutorial is noticed by the majority of the participants but is not as accurately remembered as an explicit performance task.

The participants have been tested on their knowledge to disconnect the high voltage system components in the electric car. In the quiz they were given the same set of steps that are provided on the instruction screen in the virtual tutorial and asked to order them according to the correct execution order. The steps can be seen in Fig 9.10 where they are arranged in the correct execution order, going from left to right, with the accuracy from the participants' answers shown in the percentages. Almost all of the participants

were confident about the first and the last two steps. The steps in between were also accurately arranged by the majority of the participants. This shows that the users were able to rearrange even purely textual explanations of the tasks as long as they had performed them before on their own.

Turn off the electric car	Activate the emergency disconnect switch	Secure the emergency disconnect switch with the padlock	Losen the screw on 12 V car battery	Disconnect 12 V car battery	Secure the 12 V car battery with the padlock	Remove bridge on high-voltage component	Move mechanical lock on high-voltage component	Remove cable on high-voltage component	Measure voltage on high-voltage component	Mark the electric vehicle safe to work on
93%	60%	67%	60%	60%	67%	60%	67%	67%	93%	93%

Figure 9.10.: Answers to question 6 in the "TM-VR-Schulungen" quiz

Part IV.

Results and Conclusion

10. Tutorial summary, future work and conclusion

In this thesis an example VR tutorial was implemented based on already existing industrial course "High Voltage Electric Vehicle Security". The course is a more complex educational tutorial consisting of multiple procedural tasks that the user will need to understand and follow in order to successfully accomplish his education. It is more consuming and logically demanding than existing VR courses related to simple repetitive tasks of equipment maintenance [6], assembling [2] or sorting [19]. Additionally, the course tests user experience in safety critical situations since the user can do false step putting him in a situation which is life threatening in reality. Certain repercussion of this miss step he experiences within this VR tutorial.

10.1. Investment time and costs

The VR tutorial was implemented during a period of five months of a full time employment. However, the implementation is done without any existing prior content or knowledge. It is expected that with the reuse of certain functionalities (chapter 7) or models from this project future educational tutorials could be developed drastically faster.

The VR tutorial benefits from easily movable solution since there is a minimal hardware setup necessary with the chosen Windows Mixed Reality headset. The application does not need internet connection to run but it is necessary to have a PC with at least 8GB RAM memory and a strong graphical card connected to the power outlet.

10.2. Benefits of VR tutorial

The user testing conducted with implemented VR tutorial shows positive results in regards to the user experience and memorability of course content. The users were interested and highly motivated to participate in the VR tutorial, they easily adjusted to the virtual environment and had only minor problems following the instructions in the tutorial. The short term testing of their knowledge confirmed that they were able to generalize the knowledge from the VR course and adequately apply it afterwards. This shows that not only simple tasks learned in VR can be well transferred to the real life situations, as already showed in the user study by Schleyer, Prinz and Kurth [19], but that the same effect applies on more complex material.

During the user testing none of the course participants failed the second part of the tutorial. This means that each user has followed the steps clearly and did not put himself in a dangerous situation by touching high voltage car components before they have been disconnected. This only shows that the VR instructions are clear for the users not to get them in safety critical situation but not how causing this situation would effect them. Never the less, the obvious benefit of VR tutorial compared to real world experience is that the user is able to make this mistake without the danger of personal injures.

In order to organize traditional "High Voltage Electric Vehicle Security" course, the instructor has to wait for the time when an electric vehicle is available to him. He needs to collect course participants and organize a trip with them to the work space where the car is parked. With the VR tutorial, the course can be organized at any convenient time in any chosen space. The room has to be big enough to fulfill the minimum play area requirements for the VR headsets but the setup of play area takes only couple of minutes. However, to avoid possible problems with motion controllers' tracking it would be advisable not to expose controllers to strong, directed, natural light.

10.3. Limitations of VR tutorial

The VR tutorial is implemented as a single person experience. Only one user is able to go through the course content at the time. Because of the complexity of course material, the duration of the course is longer than originally planned and it is necessary to plan 30 minutes of VR experience per user. The traditional course could have been conducted with multiple participants in the same time. In order to be able to produce the same conditions with VR tutorial, an investment in multiple equipment (PC and a VR headset) instances is required. Each user in the VR application will need his own dedicated space for mapping virtual environment to real word and with the increase of simultaneous VR tutorial executions more room space has to be planned.

In the room-scale virtual reality setup, the user defines the borders of the virtual world. Once he gets close to these limits, they will be subtle displayed in the application. However, it is possible that the users who are new to the VR experience might not react to this warning. In order to additionally secure the users from running into physical barriers, the room where the virtual tutorial is conducted should be cleared from any objects the user could run into accidentally. The soft objects could be placed between user and walls to avoid accidental equipment damage.

Finally, the information given in the VR tutorial only in picture or textual format did not show any benefits over the same information provided on the peace of paper. However, the users did feel animated by the tutorial content to pay attention even to the information which was not explicitly asked from them, as seen by the correct answers to the question about "rescue safety hook" in the quiz.

10.4. Future work

This VR tutorial was a redesign of an existing course with the focus on task execution and functionality implementation. The minimal amount of time was invested to optimize 3D models, textures and materials in the application. Working further on this aspect could improve realistic feel of the virtual objects. The same effect can be accomplished with better light adjustments in the virtual world.

In this example of virtual tutorial only the visual effects have been explored. Adding haptic feedback to the motion controllers could improve the assessment of distance within the virtual world. If the controller would vibrate when the virtual object is touched or when object was marked, it would help the user faster realize that he has performed certain action or is interacting with the object.

Finally, certain small actions could greatly benefit from the addition of sound in the virtual tutorial. Good example would be the opening of an emergency disconnect switch. It was clear during the user study that participants took longer than necessary to open the emergency disconnect switch because they were uncertain at which point they have accomplished this correctly. If the switch would produce clicking sound when it has been opened up it would be clear indication to the user that he changed the state of this object as required.

10.5. Conclusion

In order to build an education virtual tutorials certain investments in regards to both time and money are necessary. This thesis demonstrates that it is possible to redesign an industrial course with this technology in the period of half a year. The necessary accompanying hardware can be acquired at reasonable price. Furthermore, the benefits that this solution can offer to the company and its employees makes this investment strongly suggested to consider. The VR tutorial can offer hands on experience for simple and more complex procedural tasks, on different content topic and can reproduce realistic simulations of safety critical situations. Once completed, the course can be organised easily at different locations and without the necessity to wait for the equipment to become available. Regarding all the benefits that this technology brings and the ever smaller investment costs necessary, it is very likely that more companies will consider investing into this future type of industrial education.

Appendix

A. Detailed Descriptions

Bibliography

- [1] Unreal Engine 4. What is unreal engine 4? [UE4 link](#). Accessed: 2019-02-14.
- [2] Helmuth Trefftz Amaury Peniche, Christian Diaz and Gabriel Paramo. An immersive virtual reality training system for mechanical assembly. *Proceedings of the 4th International Conference on Manufacturing Engineering, Quality and Production Systems, -(-):-*, 2011.
- [3] Justin Filippou Christopher Cheong and France Cheong. Towards the gamification of learning: Investigating student perceptions of game elements. *Journal of Information Systems Education*, Vol. 25(3):233–244, 2014.
- [4] BENNING Elektrotechnik & Elektronik GmbH & Co.KG. Duspol expert manual, 2006.
- [5] Unity community. Unity asset store. [Unity Asset Store link](#). Accessed: 2019-02-14.
- [6] Xulio Fernandez Hermida David Martnez Oliveira, Sandra Castro Cao and Fernando Martn Rodrguez. Virtual reality system for industrial training. *IEEE International Symposium on Industrial Electronics, -(-):1715–1720*, 2007.
- [7] Vincent G. Duffy Fuhua Lin, Lan Ye and Chuan-Jun Su. Developing virtual environments for industrial training. *Information Science*, Vol. 140(1-2):153–170, 2002.
- [8] BMW AG Munich Germany. Bmw i3 emergency responders guide, 2013.
- [9] BMW AG Munich Germany. I01 high-voltage components, 2013.
- [10] HTC. Seated vr experience. https://xinreality.com/wiki/Seated_VR. Accessed: 2019-02-13.
- [11] HTC. Vive virtual reality system. www.vive.com. Accessed: 2019-02-11.
- [12] Jaffrey Earp Ilaria Caponetto and Michela Ott. Gamefication and education: A literature review. *The 8th European Conference on Games Based Learning*, Vol. 1(1):50–57, 2014.
- [13] Mohammad Ali Mirzaei Jean-Rmy Chardonnet and Frdric Merienne. Visually induced motion sickness estimation and prediction in virtual reality using frequency

- components analysis of postural sway signal. *International Conference on Artificial Reality and Telexistence Eurographics Symposium on Virtual Environments*, Vol. 1(1):9–16, 2015.
- [14] Behrang Keshavarz and Heiko Hecht. Visually induced motion sickness and presence in videogames: The role of sound. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, Vol. 56(1):1763–1767, 2012.
- [15] TOTAL Lockout. Safety rescue hook, all you need to know, 2018.
- [16] Michael E. McCauley and Thomas J. Sharkey. Cybersickness: Perception of self-motion in virtual environment. *Presence Teleoperators & Virtual Environments*, Vol. 1(3):311–318, 1992.
- [17] Microsoft. Windows mixed reality. www.microsoft.com. Accessed: 2019-02-11.
- [18] Jared Newman and Brad Chacos. Htc vive vs. oculus rift vs. windows mixed reality: What’s the difference?, 2018.
- [19] Carsten Schleyer Niculin Prinz and Marcus Kurth. Analysis and verification of the effectiveness and efficiency of virtual reality training. *IEEE International Conference on Engineering, Technology and Innovation (ICE/ITMC)*, -(-):1–6, 2018.
- [20] none. Example video of leapmotion ui system in vr, 2018.
- [21] none. Microsoft mixed reality motion controllers, 2018.
- [22] Joseph Psotka. Immersive training systems: Virtual reality and education and training. *Instructional Science*, Vol. 23(5-6):405–431, 1995.
- [23] Robert Wilde (Siemens). Training in ar and vr. [AWE Siemens youtube](https://www.youtube.com/watch?v=...). Accessed: 2019-02-13.
- [24] Unimersiv. Professional training vr. <https://unimersiv.com/professional-training-vr/>. Accessed: 2019-02-13.
- [25] Upknowledge. Virtual reality (vr) training real benefits. <https://www.upknowledge.com/vr>. Accessed: 2019-02-13.
- [26] Wikipedia. Unity (game engine). [Unity wiki page](https://en.wikipedia.org/wiki/Unity_(game_engine)). Accessed: 2019-02-14.
- [27] Xinreality. Room-scale vr experience. [room-scale VR link](https://xinreality.com/wiki/Room-scale_VR). Accessed: 2019-02-13.
- [28] Xinreality. Standing vr experience. https://xinreality.com/wiki/Standing_VR. Accessed: 2019-02-13.