The Playful Experience Within Virtual Reality

The imagination is limitless

CMGT Game Engineering

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1 Abstract

For this thesis, an immersive 2D painting experience was developed that uses an intuitive interface with trackable painting equipment in Virtual Reality. For the immersion, the standard HTC Vive Controllers needed to be replaced with painting equipment. Through the use of desk research, interviewing an expert of electronics, the most optimal hardware was determined for the replacement. For the intuitive interface, digital artists were consulted to create a focus group to determine which essential tools and functionalities were required. Through prototyping, testing and observation evaluations were made, and multiple iterations were developed to realize the experience. This was all done for the goal of developing a demonstrator for Saxion's XR Lab.

2 Preface

While working on this thesis and project, I got to work with the equipment I had never experimented with before. I am grateful for the opportunity given by Matthijs van Veen to work on this project. By exceeding my previous experience in Virtual Reality and intuitive development, I was able to develop my version of the Playful palette and use it to create my very own painting application with interactive electronic devices. Creativity is truly limitless, and it shows with creating art and new products alike. Even during these trying times, I would like to thank my family and friends, the graduation group of Kasper Kamperman and Johannes de Boer, and once again Matthijs van Veen for the support, effort and guidance helping to create this application.

Have a nice read, and stay healthy!

Elias Elkhoury, 2020

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3 Introduction

With Virtual Reality (VR), digital painting on 2D canvases is now extending to 3D spaces. Google's Tilt Brush and Oculus Quill are widely accepted tools among artists that pave the way to a new form of art - 3D immersive painting (Kim, Kim, Kim, & Kim, 2017).

That does not mean that 2D painting in VR is in the past. According to Arora and colleagues (2017), precisely sketching the intended strokes in mid-air can be a challenge. Adding to this, they conducted a study comparing traditional sketching on a solid surface to drawing in VR, with and without a solid surface to rest the stylus. The result indicated that the lack of a physical drawing surface is a significant cause of inaccuracies in VR drawing and that the effect is dependent on the orientation of the drawing surface.

However, what does it take to create a 2D immersive painting application? To add more to the immersion and aiding with painting in VR, would the implementation of a trackable palette, brush, and canvas in VR make a difference? Could the implementation of Adobe's interactive color picker, The Playful Palette, be of any beneficial use? Research is required to answer these questions.

3.1 Document Structure

The purpose of this thesis is to provide an overview of the research that has conducted and concluded for the project, the Playful Painting VR Experience. The layout of the company, the objectives of the client, as well as the preliminary problems are addressed first.

Secondly, the thesis will focus on the required knowledge needed to research for the assignment. A written literature study it will go over Adobe's Playful Palette, existing reviews about hardware equipment replacing the standard VR headset controllers, the complexity of the brush, and the functionality and interface required for the experience.

Thirdly, addressing the problem definition with the insight gained from the literature study. The formulated main and sub-questions will follow after; then, it will go over to scope, which contains the limitations set for the project.

Fourthly, the focus will be on the methods for obtaining knowledge to answer the main and sub-questions, followed by the results from the methods used.

Finally, the focus will be on the conclusion, discussion and recommendations made based on the obtained results and development of the prototype.

4 The Client

4.1 The Saxion XR Lab

The Extended Reality (XR) Lab is a quickly growing and adapting location in which Matthijs van Veen is in charge. The site of the lab is on the first floor at Ariënsplein, Enschede. The primary goal of the lab is to create a connection between education, research, and the industry in the area of XR, gaming, and storytelling. It should come to no surprise that knowledge development is one of the spearpoints of the lab. It has a strong affiliation with Saxion's research groups like Ambient Intelligence, allowing the projects from these groups to be offered to the Creative Media and Game Technology (CMGT) Saxion Smart Solution and Minor Immersive Media students to do research and develop them. Since the start of the school year 2019/2020, the XR Lab had its official opening. Ever since then, the number of projects available and companies wanting to work with the lab has increased immensely.

The lab offers a lot of opportunities to use many types of equipment that are usually unavailable for all the students, such as the High Tech Computer (HTC) Vive Pro Headset (Figure 1), which this project uses to enhance the VR experience. The lab offers the necessary space for students to work on these projects there for the whole year. However, not only the CMGT Saxion Smart Solution and Minor Immersive Media students but Graduate students and other students can make use of the lab as well.

Figure 1: HTC Vive Pro with controllers and lighthouses (Vive, 2018)

5 The Reason

Even before the official opening of the lab, the client had various clients come over to see how the lab was operating and also held events to demonstrate what the lab is capable of producing together with the students. For demonstration purposes, the projects that students were developing would be used during these events and visits. However, this was a slight problem because a lot of these projects were still in development, which means that the client was not able to show the full capabilities of the lab. The client would like to have projects that are finished and be able to demonstrate them during events and company visits. The client is then capable of showing not only possibilities within XR Lab but what the students are capable of as well. That is the reason why the client had set up this assignment that would lead to a fun experience. In this case, an immersive 2D painting application that makes use of a trackable palette, brush, and canvas in VR, which has Adobe's Playful Palette color picker implemented.

6 Objective of the Client

Before defining the problem, the objective of the client must be made clear. The client's objective is as follows: "How do you create an immersive VR Experience with an intuitive interface where the artist can use an actual palette and brush to paint on a canvas with Playful Palette implemented?"

6.1 The Products

The final product can be visualized by basing the question and the reason mentioned above. The final product is an immersive VR Experience for artists of all ages that can use a trackable palette and brush to paint with the use of Playful Palette. However, this product can be broken down into several products to have a better overview.

The first product is a recreation of Playful Palette within VR, the second product is the hardware, which exists out of a trackable palette and brush that are in VR. The third product is an intuitive interface that is user-friendly and easy to use for the artist. When all these products are combined, they will lead to the final product.

6.2 The Stakeholders

For this research, the identified stakeholders are the following:

6.2.1 The Client & The Demonstrator.

The client would like to have a demonstrator and this project, an immersive painting VR experience, will be used for that purpose. This project demonstrates what the students are capable of in the Saxion XR Lab with the right equipment and tools provided.

6.2.2 The Traditional & Digital Artist.

The client agreed that the artists who are being focused on are digital artists as well as traditional artists varying from age. Traditional artists that try to paint on any digitalized tool tend to find it difficult or are discouraged from getting into it because of the way painting software use RGB values (Shugrina, Lu, & Diverdi, 2017). As for digital artists, it will create new ways to visualize their arts from different perspectives instead of drawing on a tablet.

6.3 Limitations

Together with the client, boundaries were made to ensure that the project stays on the right track. The first limitation being artists to be able to draw in the experience using only a palette and a brush that should be trackable in VR. The art drawn should be in 2D and be able to simulate the same feeling as painting in real life. Secondly, going into 3D must be avoided as this has been done by many other applications before, for example, Google's Tilt Brush, which is known to be a VR painting experience that allows the users to paint in 3D.

Finally, the number of functionalities within the application must be limited. It should be a straightforward painting application, no need for the excessive function that Photoshop has. Besides these limitations, the project can take any approach to realize the desired product at the end of the semester.

7 Preliminary Problem

As mentioned before, the client wants a painting application developed in VR using original painting equipment and utilizing Playful Palette. However, the identified problem is that the knowledge of developing the said application is lacking. What can be done right now is to identify several specific problem areas basing on the objectives of the client.

The first specific problem area is the tracking of the painting equipment and canvas in VR. To have an immersive experience, the original painting equipment, those being the brush and palette, are going to replace the standard controllers that are part of the HTC Vive Pro headset. How to make these tools trackable in VR is currently unknown.

The second is mimicking the brush's functionality, the current knowledge of how to execute the visualization and implementation of the brushstroke in VR is lacking.

The third is the implementation and usefulness of the Playful Palette, the current knowledge of how to implement the color picker is lacking. It is also unclear how beneficial the color picker will be within the painting application.

The last one is the functionality and interface needed for the painting application. Considering everything will be done on the palette, it is unclear how the visualization on the said palette will be and what the most optimal and user-friendly use for the interface will be.

The main factor of each problem is that the knowledge about them is currently lacking. Once all the existing knowledge gap within these areas has reached the desired understanding can the issues be resolved which will it lead to the final product and meet with the client's condition of satisfaction.

8 Theoretical Framework

In recent years a lot of advancements in Virtual and Augmented Reality devices have spurred considerable public interest in utilizing the technology for design applications. Realistic haptic feedback plays a crucial factor in obtaining immersive VR Experience. However, the advancement of designing user-friendly control interfaces in VR remains to this day a slow pace. The controllers that come with the VR headset have a fixed shape and weight, and thus cannot provide realistic haptic feedback when interacting with virtual objects in VR (Chang, Huang, Chen, Chen, Peng, Hu, Yao & Chu, 2018). Therefore, this literature study will focus on hardware systems that replace the standard Vive controllers. In addition, this study will focus on realistic haptic feedback of the brush, the implementation and usage of the Playful Palette, and the interface and functionality required for the experience.

8.1 Compatible hardware systems

Ungrounded haptic devices for VR applications cannot convincingly render the sensations of a grasped virtual object's rigidity and weight. (Choi, Culbertson, Miller, Olwal, & Follmer, 2017). Choi and colleagues (2017) have presented Grabity (Figure 2) as a solution, Grabity is a wearable haptic device designed to simulate kinesthetic pad opposition grip forces and weight for grasping virtual objects in VR. The device is mounted on the index finger and thumb and enables precision grasps with a wide range of motion.
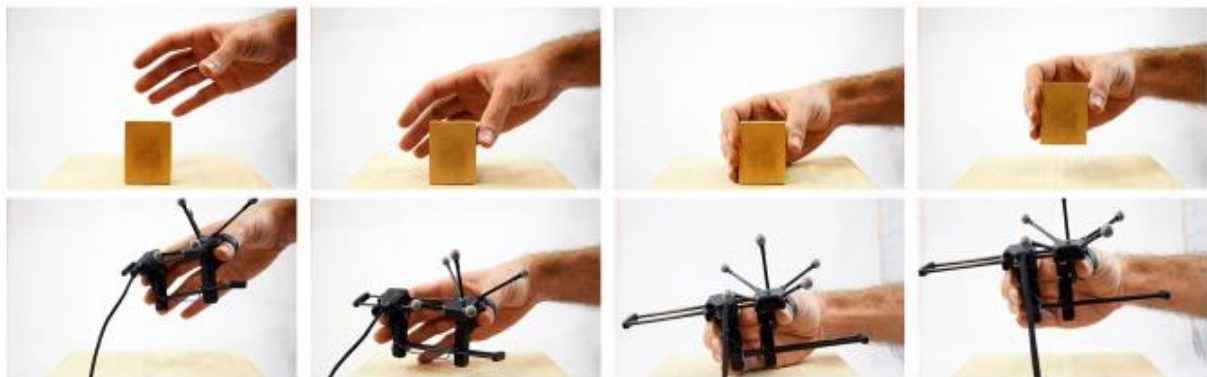

Figure 2: The use of Grabity (Choi et al., 2017, p. 1)

As Choi and colleagues (2017) state that the gripper-style haptic device is as an impressive solution, Chang and colleagues (2018) find that the mechanism might be too sophisticated to generalize to arbitrary objects. Chang and colleagues (2018) presented an object tracking system that is lightweight, easy to set up, and is capable of achieving realistic haptic feedback when manipulating objects in VR. An efficient object tracking performance has been made by taking advantage of the Leap Motion and Inertial Measurement Unit (IMU) sensor for hand tracking and deriving the object's orientation, respectively.

While this system shows great achievements, limiting factors have been pointed out by the authors. Firstly, the system is unable to track the object's position when the user has let go of the object. Secondly, the working area of the track system is limited to the sensible range of the Leap Motion controller. Lastly, the user is unable to switch between holding hands after holding the object. Despite the limitations in functionality, the system offers an excellent solution for tracking equipment that is not standard use in VR experiences.

Figure 3-4: Object tracking lightweight system (Chang et al., 2018, p. 1-2)

8.2 The Brush

A brush is many times more complicated than a pen, which presents a considerable challenge for the interested in mimicking the functionality of it. According to Guo and colleagues (2015), the brush stroke is defined by the users as a list of positions and pressure samples. However, the physical model of the brush has not been considered, which has an impact on the effects of the brush stroke. Additionally, Guo and colleagues (2015) have researched many methods of which each proposed impressive solutions. However, these methods do not refer to the force feedback technology, which can effectively enhance reality to users during the virtual painting process.

As the authors state that an expressive brush model is beneficial to the simulation of the brush stroke in the virtual painting process, they first adopted a new brush model based on various research studies to simulate the brush deformation according to the force exerted on it. Different effects of the brush stroke were affected by controlling the magnitude and direction of the force exerted on the brush. Based on the hardware component, Guo and colleagues (2015) have established the virtual painting system based on the force feedback technology. With this, different effects of the brush strokes with the pressure of various magnitudes and painting techniques are simulated in real-time, which effectively enhanced reality to users.

8.3 Playful Palette

Motivated by a pilot study of how artists interact with paint palettes before painting, Shugrina, Lu, and Diverdi (2017) created the Playful Palette to be used as a color picker interface for digital painting programs that takes the cue from oil paint and watercolor palettes. This interface is designed to support the variant tasks artists use paint palettes for, while a secure interaction mechanism allows for expeditious exploration and creative inspiration. The Playful Palette exists out of several color blobs that blend with nearby blobs to explore new arrangements and harmonies between colors. The edits made in this interface are non-destructive, and an infinite history allows previous palettes to be revisited and modified, recoloring the painting.
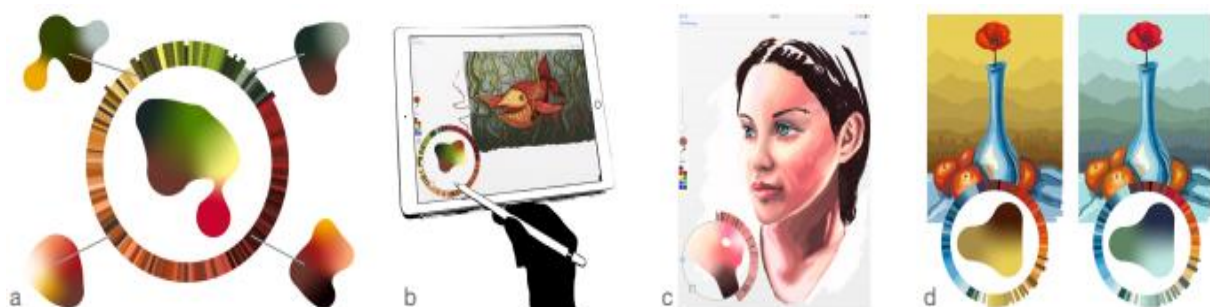

Figure 5:Adobe's Playful Palette (Shugrina, Lu & Diverdi, 2017, p. 1)

According to Shugrina, Lu, and Diverdi (2017), directly supporting the color selection need of digital painters and make the artist more creative are the two primary goals of the Playful Palette interface. The authors performed two user studies. The first being a prototype digital painting app with the Playful Palette interface that artists can try out. The second, an evaluation of the said interface to indicate if the Playful Palette is indeed beneficial. Based on these user studies, the two primary goals of the Playful Palette are confirmed to be accurate as the interface had the effectiveness of achieving the artist's color goals and amplifying their creativity.

In the research study constructed by van der Meulen and Onofre (2018) can similar findings be found. This study implements a basic version of the Playful Palette using web technologies. It was hypothesized that this implementation would make UI designers more creative and productive. Conducting user tests resulted in an indication that integrating Playful Palette into modern UI/UX design tools could benefit UI/UX designers. Even though the results are statistically significant, this study cannot be generalized due to only having three users for their user study.

8.4 Interface and Functionality

Direct painting interfaces are both intuitive and straightforward. The act of applying digital paint to a digital canvas is closely analogous to the law of applying real paint to a real canvas. Every industry-standard image creation and design tools such as Adobe Photoshop and Adobe Illustrator allow the user to make marks on a digital canvas by applying digital paint (Ritter, Li, Curless, Agrawala, & Salesin, 2006). Whether a painting interface is intuitive and straightforward depends on several factors.

Firstly, it depends on the familiarity of the features. A study conducted by Blackler, Popovic, and Mahar (2003) found that prior exposure to products that contain similar characteristics (e.g., the universal symbol for saving) supported participants to complete various tasks more rapidly and intuitively. Moreover, familiar features were used more often intuitively than unfamiliar features. Especially appearances such as shape, size, and the labeling of buttons seemed to have a positive effect on the user.

Secondly, the use of the interface is dependent on the age of the user. A significant difference in time was found between age groups. The younger participants were able to complete tasks more quickly than the older participants. Additionally, the older age group completed the tasks significantly unintuitive. These results indicate that when implementing the interface, age and familiarity of the symbols should be taken into consideration.

9 Problem Definition

With the insight gained from Chapter 8 "Theoretical Framework", the preliminary problem has not changed. It is still unknown how this application can be developed. However, the previously mentioned problem areas do not seem as severe. Starting with the first one, the tracking of the painting equipment and canvas in VR. It has been concluded that the standard controllers can be replaced with compatible hardware, such as the Leap Motion Controller and IMU sensor, even with the limiting factors. However, further research is required on whether there is better equipment that might be more suitable for the experience.

The second problem was mimicking the brush's functionality in VR. Through the literature study, it has been made clear that it can be done; however, just like with the first problem, further research is required to determine the optimal feedback.

The third problem area was the implementation of the Playful Palette within VR. With the theoretical framework, it has been concluded that this feature can be implemented and is beneficial for the artist to use. The palette has become less of a problem that needs any additional research but more of a problem that it requires time to be implemented.

The last problem was the functionality and interface needed for the painting application. It has been made clear that familiarity with many tools and the age of the user must be factored in when developing an intuitive interface. However, which desired functions and features should be in the experience still needs to be determined.

Now that it more clear on what needs to be researched upon further, these problems can be formulated as sub-questions to answer the main question. Which can be expressed as "How do you develop an immersive 2D painting application that uses an intuitive interface with trackable painting equipment for traditional and digital artists in Virtual Reality?"

10 Main Question & Sub-Questions

The main question can be formulated as the following based on the problem definition and the client's desires: "How do you develop an immersive 2D painting application that uses an intuitive interface with trackable painting equipment for traditional and digital artists in Virtual Reality?"

The following sub-questions can be formulated with the specific problem areas defined in the problem definition and help develop the final product for the client:

- Which digital painting tools and interactions are needed to make the experience intuitive and easy to use?
- Which interactive electronic hardware equipment is required to help enhance the immersion of the experience?

The last question to be asked will be about the value of the experience, as it has been concluded in the literature study, the implementation of the Playful Palette did indeed make the artists involved with the research more efficient and supported them with the need of color selection. Will the same effect take place within this experience for people that are not artistic. Which is why the following question is formulated:

- Does the immersive 2D painting experience with the use of Playful Palette support the average users' painting skills?

11 Scope

Specific limitations have been set together with the client; these are listed together under Chapter 11 "Objective of the client." Besides those, there are few more limiting factors to be wary.

The first limitation is time. There are a lot of features that can be implemented and a lot of research to be done. However, this all cannot be done within a semester. Playful palette on its own will take time to be implemented and should be the primary feature to be developed. Working on the other features such as intuitive interface and the functionality will only happen after the Playful Palette has been fully realized. Considering testing and prototyping, they should be done and released on a bi-weekly standard too keep up with the planning established in the implementation plan.

The second limitation is the number of functionalities that the interface will have within this experience. The current limit has been placed at ten various functionalities for now. However, this limit can be changed to compensate for time if it takes a lot to develop these features. Considering the hardware has a greater priority than these features, even the basic functionality of the interface should suffice the needs of the target audience.

The third limitation is getting in touch with enough artists that would want to test this experience. There might not be a lot of artists who have worked with paint before. However, this could work as a benefit for this project to see if even inexperienced users/beginners can be introduced to digital painting.

Lastly, a limit on the hardware, while research still has to be done, it can already be concluded that in this time frame, only the most promising hardware equipment will be researched on and experimented with for this project. There is no time to strive too far from the client's goal and try out various tools, hoping to see if they would work or not.

12 Method

Prototypes are widely recognized to be a core means of exploring and expressing designs for interactive computer artifacts. It is common to build prototypes to represent different states of evolving design and to explore options (Houde & Hill, 1997). Which is why for this thesis, a prototype will be created and used to prove that the research and discoveries made are valid and help answer the sub-questions.

12.1 Basic Setup

The basic setup for the project is the following: Unity3D version 2019.3f1 is the game engine where the project development takes place. The HTC VR Headset is the default hardware equipment, including the controllers as well. This basic setup will adapt to meet the results obtained after prototyping and experimenting and will be the newest version of the prototype (Figure 6). With this basic setup, it is possible to draw with the controllers on meshes with RayCasting. The color picker is a free color picker from the AssetStore that is typically for 2D development. However, it has been adapted to work in VR.

Figure 6: The starting hardware setup

12.2 Tracking of equipment

To determine which hardware is best equipped for replacing the standard Vive controllers, additional research is required. However, there are many available options but not enough time to research and test them all and determine which is the most optimal. To narrow down the available hardware guidance within this field of electronics is needed. That is why conducting an interview, and a brainstorming session with an expert within this field is required. The expert, Harry Sanderink, is a teacher at Saxion University of Applied Sciences, with his years of expertise within this field it should be possible to narrow down the most optimal hardware.

The goal of this combined interview and brainstorming session is not only to gather information about the interactive electronics but gain more insight into how they work as well. It will help gain clarity on which hardware exists that could track the external equipment in Unity and if there are any limitations when it comes to these interactive instruments. Additional desk research will be done based on the insight gained from the interview. With the acquired knowledge, it is possible to determine which electronics are most suitable for creating trackable equipment within Unity.

A comparison will be made by applying "the best, good & bad practices" from the Communication and Multimedia Design (CMD) methods (2015). By following this approach, time is saved by having a look into what others have incorporated before. It is best to learn from others' successes and failures and continue further from that than reinventing the wheel. A comparison will be made on the research and interview results where the development time, the position accuracy, and difficulty of implementing the hardware will come to light. The one that averages as best will be hardware equipment used for tracking the painting tools within the application.

12.3 Brush Functionality
In the same interview and brainstorming session, the brushstroke pressure will be addressed as well. The goal is the same as for the tracking to determine which electronic device could replicate the brushstroke pressure within the project. Once there is clarity on how and which tools could replicate the brush functionality, additional desk research will be conducted. A comparison will be made based on the research and interview results to determine the most optimal electronic to reproduce the brushstroke pressure. The comparison will be made on the functionality of the device and the way it could be implemented. Once the decision is made, the basic setup at that point will adapt to meet the result.

12.4 Intuitive interface and painting tools
Besides implementing Adobe's color picker, other essential painting tools need to be implemented. A focus group meeting will be arranged to acquire the knowledge for determining these tools. The focus group will exist out of participants who have worked in tools such as Photoshop, Gimp, ZBrush, Maya, and Illustrator before. The group exists out of four participants. One of the participants is a graduate student from the CMGT course, and the three other students are currently doing their SSS project, also from the CMGT Course. They will be asked to test the basic setup of the application. Once all of them have tested it, a meeting will be arranged where a brainstorming session will take place. The primary purpose of this brainstorm is to unanimously set the essential tools and functionalities for the painting experience that are manageable. Once the tools are determined, the basic setup will adapt to meet the results. After that, the prototype will be tested on the intuitive controls.

The usability testing model of Nielsen and Landauer (1993) will be applied to determine whether the interface is intuitive. In a typical usability-testing session, participants are asked to perform tasks, usually using one or more specific user interfaces. The researcher observes the participant's behavior and listens for feedback while they complete tasks. According to Nielsen and Landauer (1993), the amount of knowledge that can be obtained reduces as the number of participants tested increases. As stated, time is being wasted after the fifth user by observing the same findings repeatedly but not learning anything new. Therefore, the group will exist out of a total of five participants. This way, testing will be time-efficient, and multiple interfaces can be tested.

It has been made clear in Chapter 8 "Theoretical Framework" that familiarity with tools and the age of the user must be factored in when developing an intuitive interface. For reliability purposes, the chosen participants have not tried the application before. For validity purposes, participants differ in their traditional and digital drawing skills ranging from zero skills to traditional/digital artists.

Each participant will be asked a set of tasks to perform (e.g., combining color, painting a figure, save or load a painting). The behavior and feedback of the participant will be documented and reviewed. The interface will be adapted based on the feedback and tested again with the same approach and the same participants to evaluate if the changes made are better than they were before.

12.5 Supportiveness of the experience

The supportiveness of the experience will be determined once it has met the client's condition of satisfaction, those being the replaced hardware, intuitive interface, and the essential painting tools. During this phase, a user test will be conducted. The goal of this user test is to confirm if the experience supports the common users' painting skills. After the user has used the experience, they will have to fill in a questionnaire to rate their experience.

13 Results

13.1 Tracking of equipment

By having an interview with Harry Sanderink (Appendix A.), it became clear that there are many options when it comes to hardware that can replace the Vive controllers with a palette and brush. Thanks to this interview, the research obtained a specific direction to look into, and the research required got narrowed down.

According to Harry, there are two objects to be concerned about when it comes to the position of the brush in real life, the brush itself and the canvas. The canvas could be set up by having an infra-red (IR) detector. The brush would only acquire an IR LED. He identified the following as IR detectors: Nintendo WII IR Bar, IR Leap Motion, Xbox Kinect camera, and an infra-red camera. Besides IR, it was mentioned that it is possible to use an accelerometer and calculate which direction the brush is going in real life.

Furthermore, the limits to these types of electronics were addressed as well. It was stated that there are always restrictions and limitations. With IR detectors, once the LED stops pointing at the camera, it will lose the position, meaning that the tracking of the brush will stop. With the accelerometer, there will be a small delay in displaying the brush in VR as the calculations need to be done before visualizing the position.

Finally, Harry added that there are more options available for tracking the position and that the options mentioned by him should only be used as a direction for additional desk research. Therefore, the focus of the desk research was laid on electronic sensors and devices that can help with replacing the Vive Controllers.

Figure 7: Leap Motion

Guna, Jakus, Pogačnik, Tomažič, and Sodnik (2014) tested the performance of the Leap Motion Controller with the aid of a professional, high-precision, fast motion tracking system. For this study, a set of static and dynamic measurements were performed with different numbers of tracking objects and configurations. According to the authors, in both the static and dynamic scenarios, there were inconsistencies with the tracking. The results of the dynamic scenario revealed the inconsistent performance of the controller, showing a significant drop in accuracy from the taken samples more than 250 mm above the controller. While in the static scenario, there were inconstancies as more distance was taken from the controller. Guna and colleagues (2014) concluded that due to the somewhat limited sensory space and inconsistent sampling frequency of the Leap Motion, it cannot be used as a professional tracking system.

Furthermore, a user study conducted by Caggianese, Gallo, and Neroni (2018) tested the difference of the Leap Motion and the standard Vive Controllers in terms of interaction design. The test involved three manipulation tasks: Walking around with a box and blocks, where the blocks need to be carried towards the goal (Figure 9a). Creating a block tower, carefully stacking up four blocks to realize a tower (Figure 9b). Ordering numbered cubes. The numbered cubes are faced away from the user; the user would have to rotate each block to see the number and proceed to put the block in order (Figure 9c).
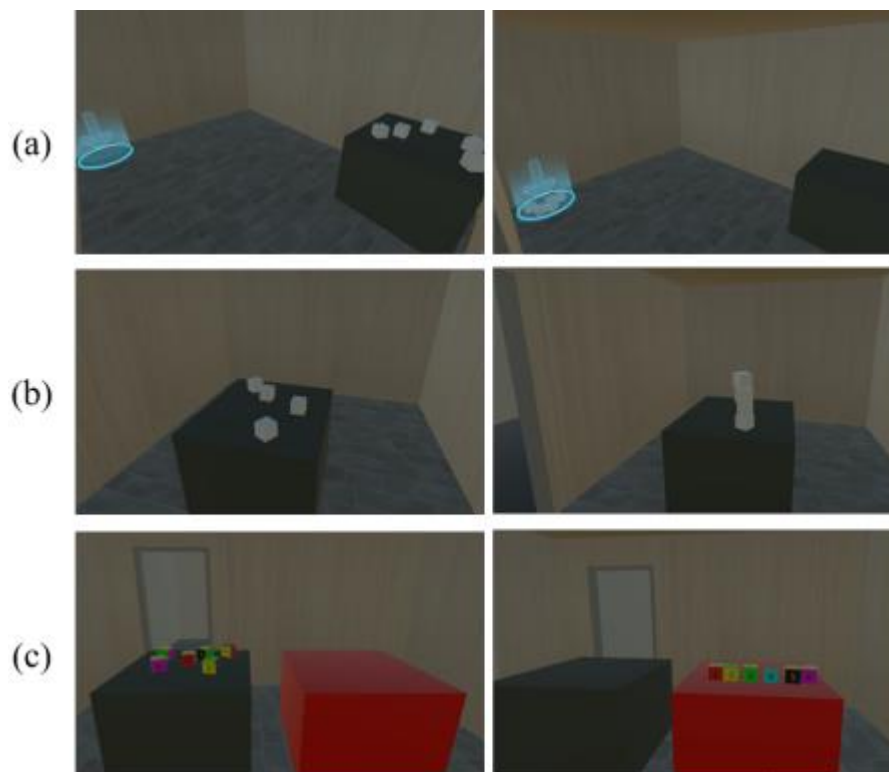

Figure 9: The manipulation tasks (Caggianese, Gallo, & Neroni, 2018)

The test revealed that the Vive Controllers had in both quantitative and qualitative terms a better performance and a lesser perceived difficulty thanks to its stability, accuracy, and lower learning curve compared to that required by the Leap Motion sensor. This conclusion is made based on the participants' perceived difficulty averaged over the three tasks when using the two devices, the scale ranging from 1 to 7, with higher scores representing the greater difficulty (Figure 10)
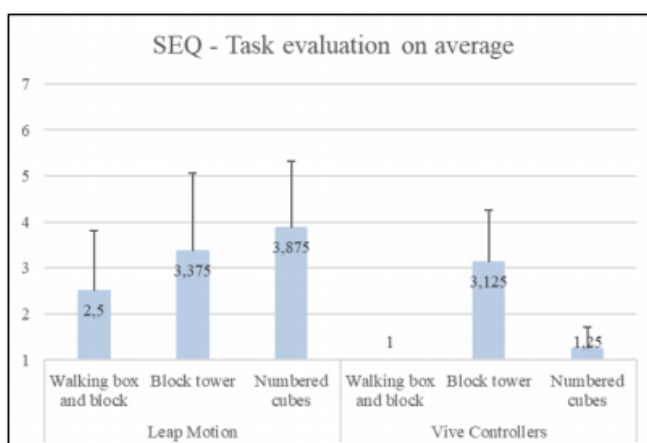

Figure 10: Test results of the tasks (Caggianese, Gallo, & Neroni, 2018)

Due to recent improvements in VR technology, the number of novel applications for entertainment, education, and rehabilitation has increased. The primary goal of these applications is to enhance the sense of belief that the user is present in the virtual environment (Caserman, Garcia-Agundez, Konrad, Göbel, & Steinmetz, 2019).

When comparing any device that comes close to the Vive Controller, there is only one: The Vive Tracker (Figure 11-12). The Vive Tracker is part of the HTC Vive headset. Compared to other research-grade systems that require additional cameras or sensors around the premise for the tracking, the tracker is a small, self-contained unit, which allows the tracking of a wide range of objects attached to it (HTC Corporation, 2019). Caserman and colleagues (2019) conducted a study where the authors compared the HTC Vive Trackers with HTC Vive Controllers to create a low-latency body tracking. The study revealed that the solution was capable of tracking both the joint rotation and position with decent accuracy, a very low end-to-latency even with a slight delay and precise tracking, it was possible to create deeper immersion.

Figure 11-12: Vive Tracker, Vive Tracker (HTC Corporation, 2019, p. 11)

13.1.1 Conclusion
While comparing the desk research results and the interview, it can be concluded that the Vive Tracker is the more optimal option to use for tracking the external position of the brush, palette, and canvas. Unlike the other devices that need additional equipment and sensors, the tracker is part of the HTC Vive headset and gets immediately detected by the headset, so when it comes to development time, there is none. The additional use of the other sensors and detectors become obsolete when it comes to tracking the rotation and position, as this is all included within the Vive Tracker (HTC Corporation, 2019).

13.2 Hardware Equipment Update Version 1

With the conclusion for the tracking of the brush, palette, and canvas, the basic setup adapted to meet the result. For this setup, the first Vive tracker was attached to a custom made paintbrush. A second tracker was attached to a palette bought from a store. Finally, a third tracker was used for positioning the canvas.

When applying this method, there was no delay when tracking the equipment, and the setup was easily implemented within Unity.

Figure 13 - 16: Improved hardware equipment and usage

13.3 Brush Functionality

For replicating the brushstroke, Harry recommended in the same interview (Appendix A.) the following sensors: Bend sensor, flex sensor. These sensors give a signal when they are bent. Thus, when the brush is near the canvas, it will provide a signal to the experience that it is allowed to draw. In addition, the use of a distance sensor is also possible; however, since it is at a short-range, a short-ranged sensor is required for this application.

When it comes to the curves of a brushstroke, it gets challenging as well; Harry added the following: It is possible to tell the curves with a tilt sensor; however, this works only with one angle. To get each angle, it would be too many tilt sensor since there are too many possibilities. As mentioned before, the options given by Harry are used as recommendations and directions to apply for the desk research. While performing desk research to obtain additional knowledge about the sensors to understand their functionality better, another sensor came to light, the Force-Sensing Resistor (FSR) sensor.
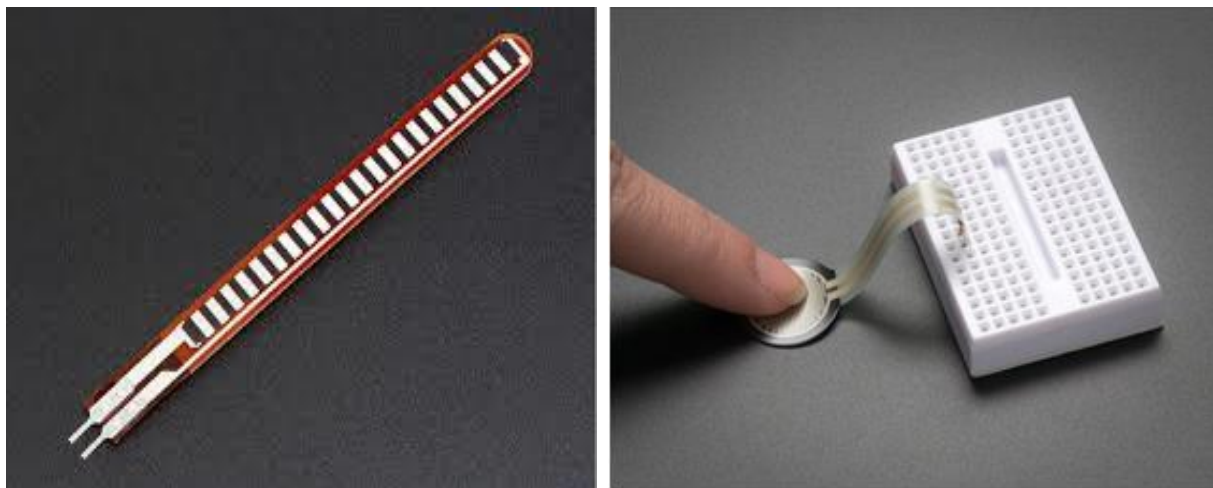

Figure 17-18: Flex Sensor and FSR sensor with breadboard

FSR sensors are devices that measure static and dynamic forces applied to a contact surface. Their range of responses depends on the variation of its electric resistance. In general, Flexiforce and Interlink are two common types of FSR sensors that are available, cheap, and easily found in the market. Studies have shown that the FSR sensors are commonly applied for robotic grippers and biomechanical fields (Sadun, Jalani, & Sukor, 2016).

A study conducted by Matthies, Haescher, Bieber, Salomon, and Urban (2016) showed the use of the FSR sensor, an accelerometer, and a Piezoelectric Transducer. The sensors were applied to the head of a ballpoint pen. The ballpoint pen was then capable of calculating an individual's heart rate when pressed on the throat of the patient. Each sensor showed the capability and sufficient accuracy for reading and analyzing the seismographic micro-eruption caused by the pulsing blood.

Figure 19-20: FSR sensor with a ballpen (Matthies et al. 2019, p. 2)

The FSR sensor was also used in a different study by Akhtaruzzaman (2019). It was used to create a smart toothbrush; the brush would indicate the best and worst situation for brushing teeth in terms of applied forces. The user would be alerted through LEDs. In both studies, the FSR was used to indicate the applied force and was deemed significantly accurate. Along with an FSR sensor, an Arduino was used.
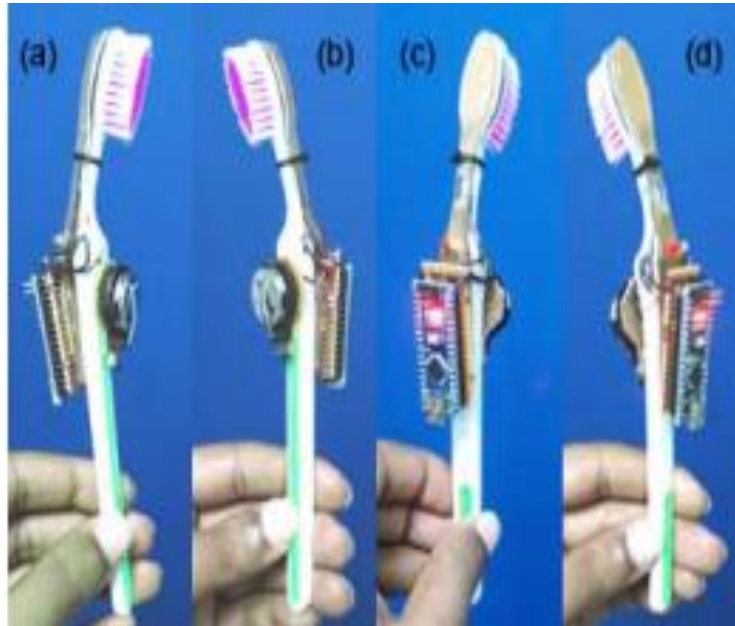
Image 21: FSR sensor with a toothbrush (Akhtaruzzaman, 2019)

An Arduino (Figure 22) is an open-source platform used for constructing and programming of electronics. It is capable of sending and receiving signals from any device; this includes Unity as well. In contrast to other programmable circuit boards, the Arduino does not have a separate piece of hardware to load new code on the board. With the use of a simple USB cable, it can be connected to the computer to be programmed. The programming language is based on C++ but simplified. (Badamasi, 2014).

Figure 22: Arduino Uno Rev3 (Arduino, 2020)

13.3.1 Conclusion

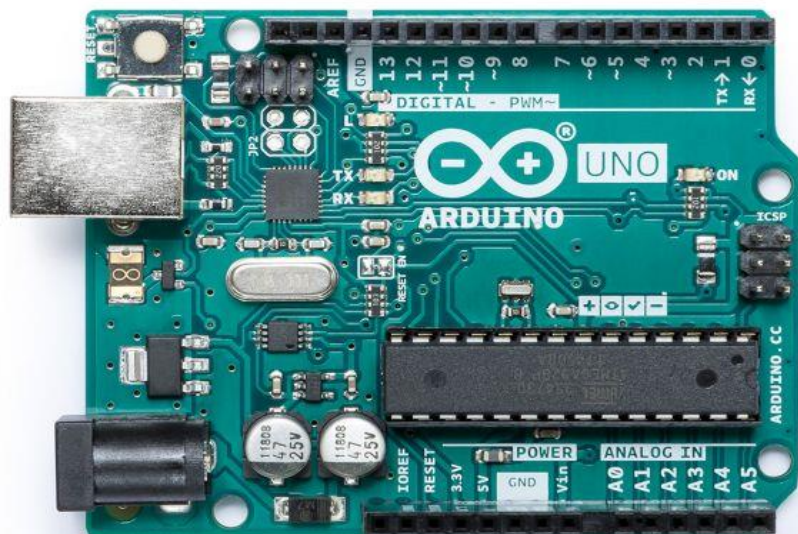With the insight gained from the interview and the additional desk research, it can be concluded that using an Arduino together with an FSR sensor is an optimal solution to get the brushstroke pressure in the VR Experience. When force is applied on the FSR sensor, it will send the output to the Arduino, which in return, will send the output towards the computer with the use of a USB cable (Badamasi, 2014). In other words, the FSR would allow brush strokes to be made in all directions, unlike the bend and flex sensor that can only bend in one direction. Meaning that if the bend or flex sensor was chosen, more sensors would have been acquired, which would make the custom paintbrush expensive and not efficient when in use.

13.4 Hardware Equipment Update Version 2

The Arduino Uno Rev3 was chosen to be attached to the custom made paintbrush. The Arduino is programmed to measure the input and send it towards Unity. Unity will convert the data to int, visualizing the brush stroke thickness in the VR experience (Figure 23).
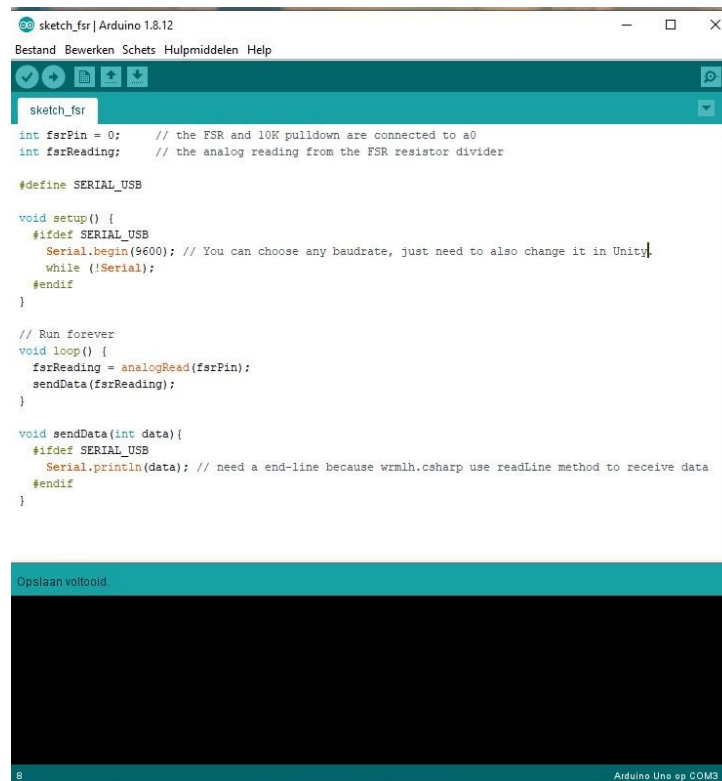
Figure 23: Sketch made in the Arduino Software

By following the layout below (Figure 24) Two wires are to linked together from the FSR to the breadboard, creating a voltage divider with 10k resistor and the force sensor, squeezing the force sensor alters the resistance so the voltage in at A0 will vary depending on the force applied.
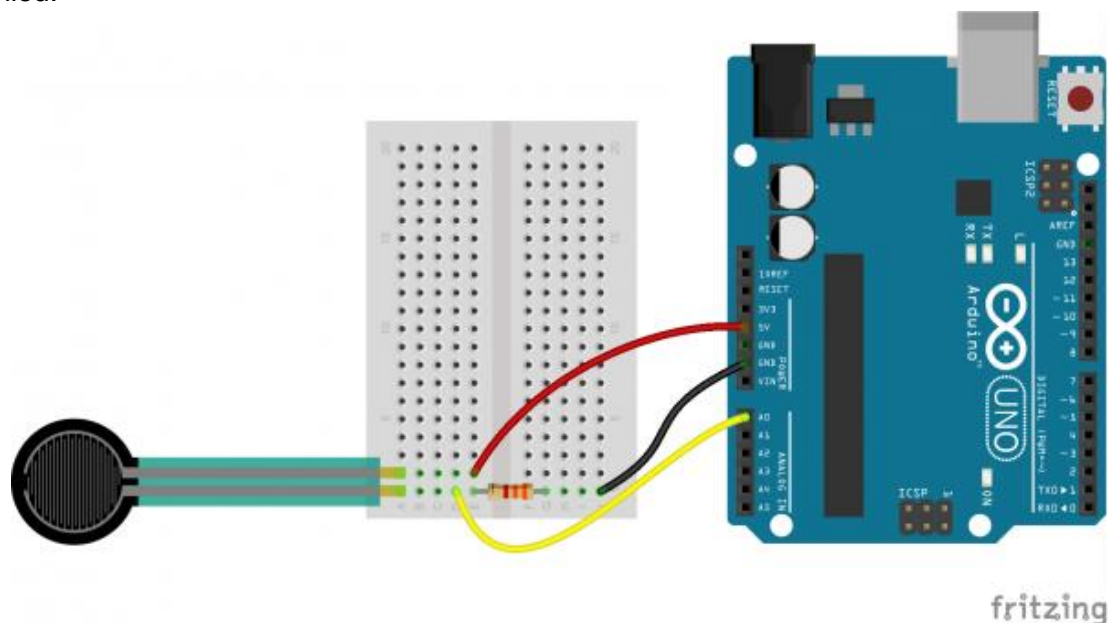
Figure 24: Layout of the FSR with Arduino Uno Rev (Lindblom, 2016)

Following the layout and attaching it to the brush will result in the setup for the custom made brush below (Figure 25 - 26).

Figure 25 -26: The Arduino setup on the custom made brush

The FSR sensor is attached to the top of the brush, and it receives the force applied on the paintbrush head (Figure 27). When using the brush, the pressure is measured by the FSR sensor and send towards the Arduino Uno.

Figure 27: Custom made brush with a brush attached

With the brush attached, it results in the Arduino reading the pressure applied when painting and visualizing in Unity (Figure 28 -29).

Figure 28: Illustrations of the paintbrush stroke thickness in Unity

Figure 29:: Illustrations of the paintbrush stroke thickness in Unity

13.5 Intuitive interface and painting tools

13.5.1 Functionalities and tools

During the group meeting with the Focus Group (Appendix B), several functionalities and tools have been identified as essenti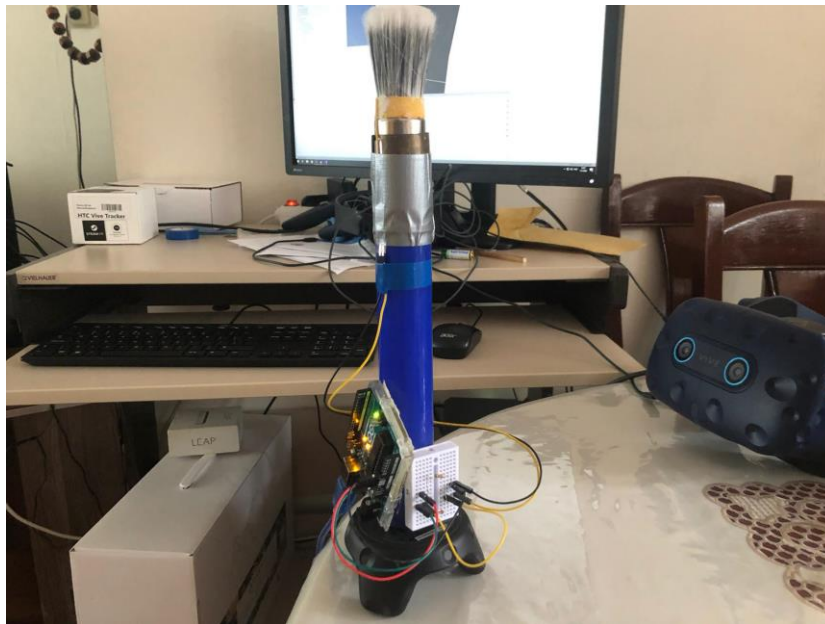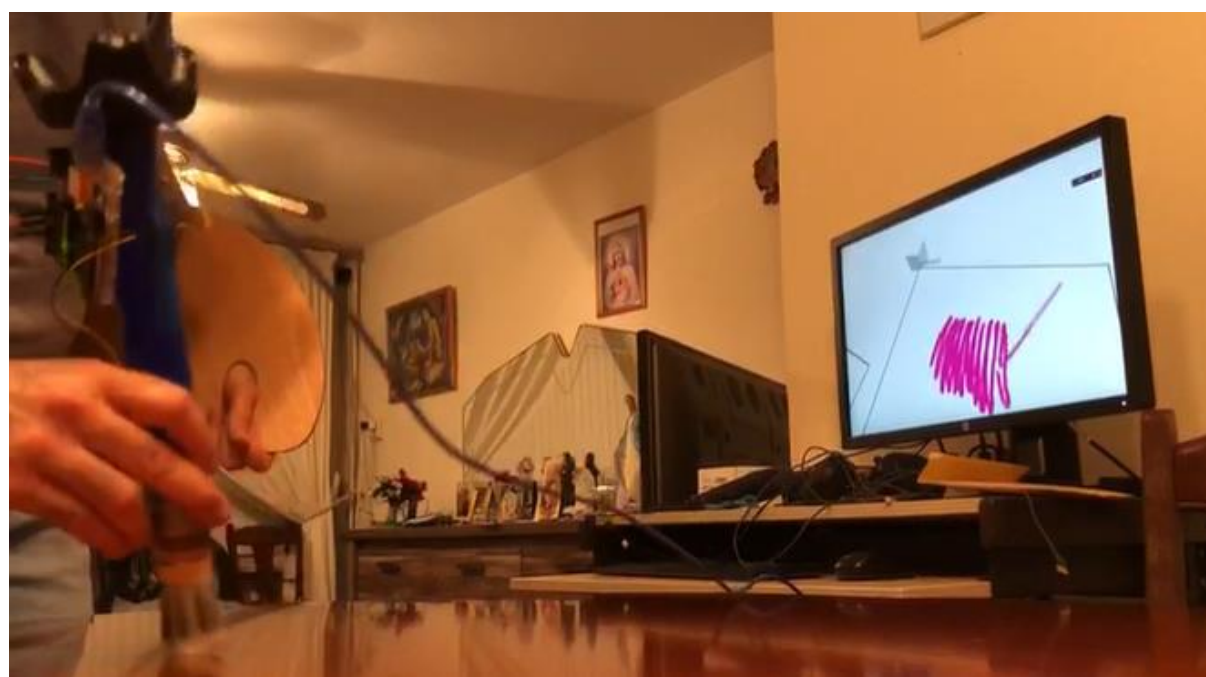al for the painting experience. Functionality-wise, the first being able to load a photo reference. According to the focus group, it would be frustrating to remove the headset regularly to look at a reference on the screen. Second, being able to create a new canvas. Instead of reloading the whole application, it is more favorable to create a canvas to paint on. Another essential functionality is the ability to save and load a painting, paste and cut, and undo and redo. The final feature to implement is layers. With layers, the user is ensured that when painting over the drawing, they will not ruin the whole painting if they make a mistake. Tool-wise, the group identified multiple brushes (e.g., pencil, spray, crayon, and fill-in) and the ability to adjust the brush size to be essential tools to have.
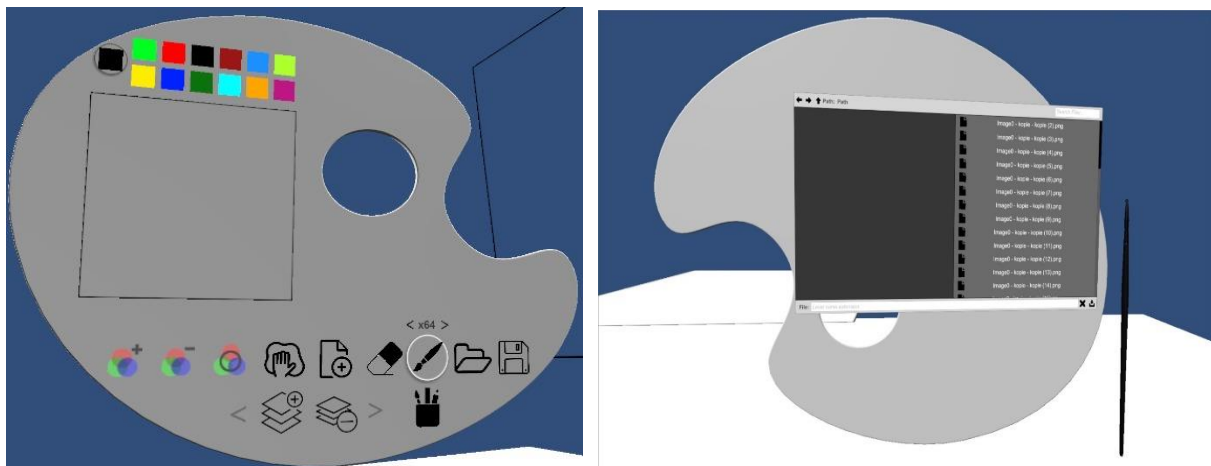

Figure 30-31: The original palette, load screen and brush

13.5.2 Usability Test 1

During the first Usability Test (Appendix C.), it was identified by documenting the participant's behavior that all the buttons were recognizable and easy to find by four of the five participants when performing the given tasks. One of them mistook the Clear Palette button with the New Canvas button.

Besides that, it was also indicated that all the participants experienced visual feedback as lacking. For example, when saving, it was not clear for any of the participants if the painting was saved, that is why most of them pressed multiple times on the save button. All participants remarked that it should indicate that the interaction with the save button was successful and the image was saved. The same feedback was given for the load button, new and delete layer button, the new canvas, and clear palette button. The visual feedback for these buttons was also lacking.

When loading, the participants had a difficult time interacting with the buttons due to the small size. In addition, the participants were not able to see if they had selected a file.

Furthermore, when selecting a color to mix with, it was not clear for the participants if they had chosen a color. Four of the participants expected an indication that they had selected a color. Additionally, selecting a mixed color was also not visually apparent. While they had already chosen the color they wanted, they attempted several times more due to them expecting some change with the brush. (e.g., they assumed that the brush would change color).

Finally, four of the five participants remarked that the buttons they interacted with were too sensitive. The button would have been pushed multiple times, overshooting their intended goal when they intended only to press once (e.g., changing the brush size). The time between interactions was so small that before they could move their brush somewhere else, the same interaction on the same spot would happen again. However, all of the participants were able to interact with the canvas and paint on it.

It became clear from the first Usability Test that despite the design for the buttons was clear and buttons were easy to find by the majority, the interaction and visual feedback did not align with the expectations of any of the participants.
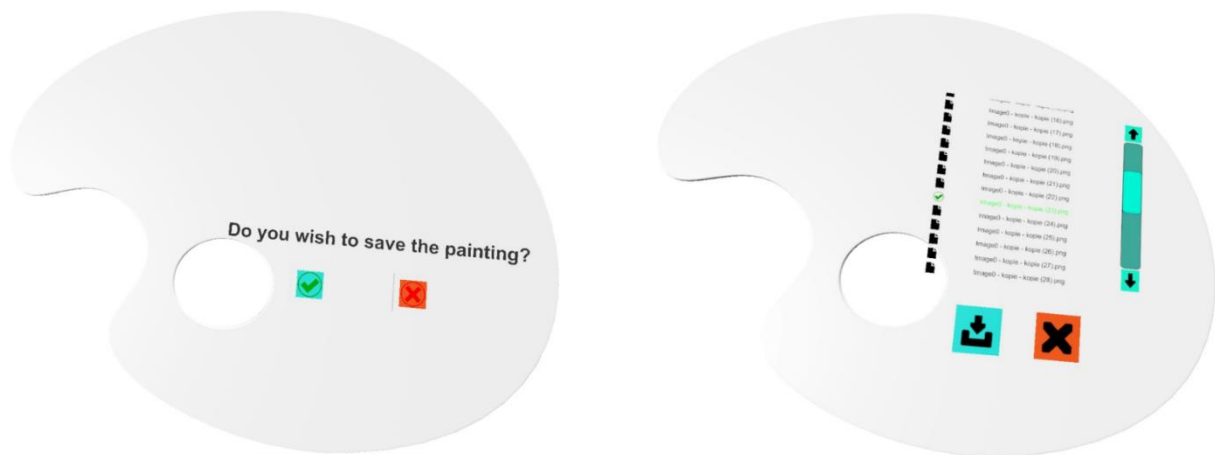
Figure 32-33: Pop up before starting a new file, Updated loading screen

13.5.3 Usability Test 2
During the second test (Appendix D.), the following was documented: The interactions with the buttons were clear for all the participants, the interaction timer with the buttons was welcomed by three of the five participants. Two added they would like to have a little smaller window since they had to wait a bit too long before they could interact with the button again. While not mentioned during the first Usability Test, one of the participants remarked that there should be an option for left-handed users. The interface for loading the images was a lot better.
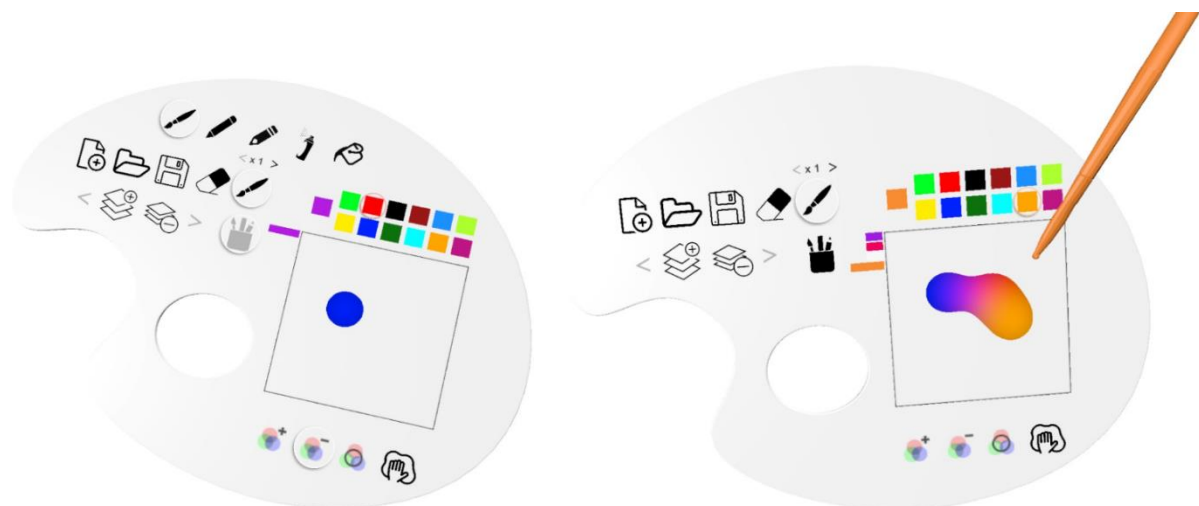
Figure 34-35: Additional tool brushes, Updated palette with color picker

13.5.4 Usability Test 3

For the third test (Appendix E.), the additional option for asking if the user is left-handed or right-handed was welcomed by all the participants. The reduced timer helped with interacting more natural with the palette. The improved color picker with a history implemented so users can select their pervious color felt pleasant to use.
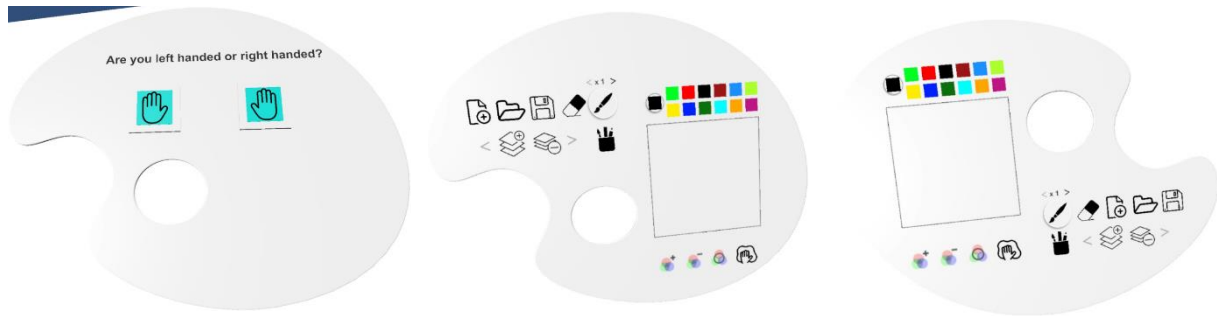
Figure 36-38: Left-handed and right-handed option, right-handed palette, left-handed palette

13.6 The supportiveness of the experience

The results from the questionnaire (Appendix F.) indicate that three of the participants found the interaction and interface of the experience very intuitive and straightforward to use. Two participants found the interaction and interface intuitive and easy to use (Figure 39).

How did the interaction and interface feel within this experience?
5 antwoorden
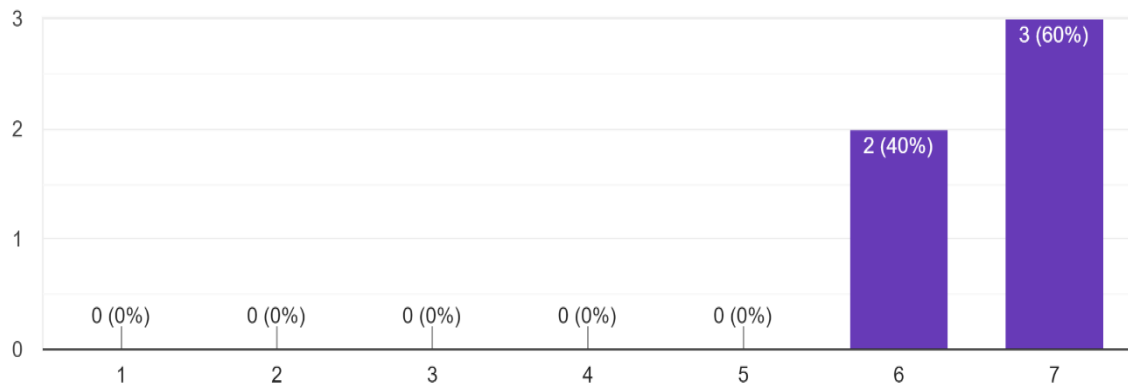
Figure 39: Interaction and interface intuitiveness score from 1 unintuitive and not easy to use to 7 extremely intuitive and very easy to use

Furthermore, three of the five participants found the use of the brush and palette within this experience very comfortable to use, while two participants found it comfortable to use (Figure 40).

How did you experience the usage of the brush and palette?
5 antwoorden
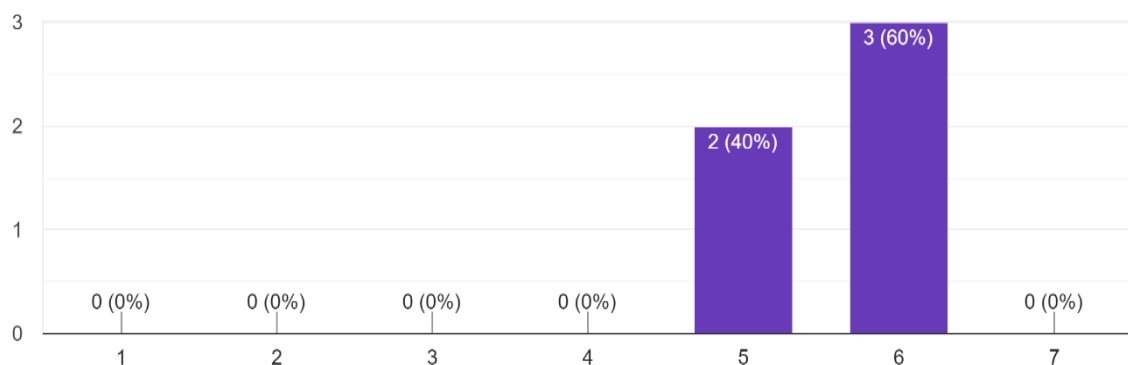
Figure 40: The brush and palette comfortableness score from 1 very uncomfortable to extremely comfortable

Additionally, three of the five participants found the use of the Playful Palette Color picker very helpful. They mentioned that the preferred colors were easily found when combining the blobs than if they had to use a slide to find the right color to use. Two participants found the color picker helpful. (Figure 41).

Did the use of the Playful Palette color picker make color choices easier?
5 antwoorden
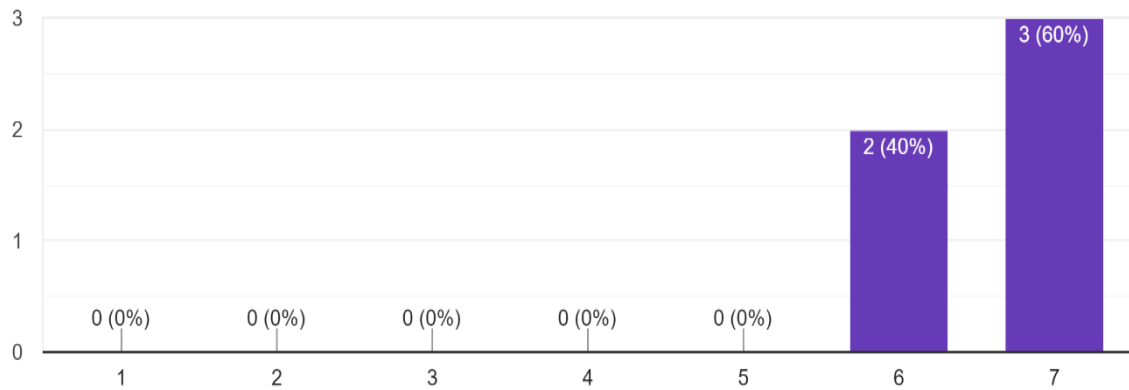
Figure 41: The Playful Palette usefulness score rate from 1 not easy to use and not beneficial to 7 very helpful and easy to use

Overall, all the participants found the experience positive and fun to use and would like to try it again someday (Figure 42).

If you could rate your overall experience, what would it be?
5 antwoorden
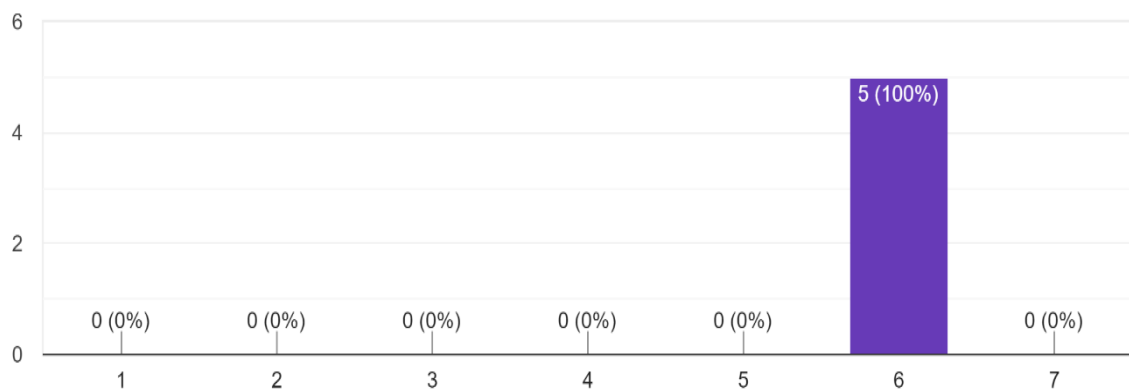
Figure 42: The overall experience rated from 1 very unpleasant to 7 very fun and want to try again

14 Conclusion

Implementing the features and developing the hardware prototype was quite a challenge to tackle. The choices made for the final implementation of the product were researched and tested thoroughly before landing on the conclusion. The questions below were the questions raised during Chapter 10 "Main and Sub-Questions" and will be answered with the results obtained in Chapter 13 "Results".

Sub-Question 1: Which digital painting tools and interactions are needed to make the experience intuitive and easy to use?

Functionality-wise, a photo reference, create a new canvas, save and load a painting and layers have been identified as essential. Tool-wise, multiple brushes (e.g., pencil, spray, crayon, and fill-in), the ability to adjust the brush size are identified as essential.

Through the use of familiar icons and visual feedback, the functionalities and tools that are implemented have been validated by the focus group to be intuitive and easy to use.

**Sub-Question 2:** Which interactive electronic hardware equipment is required to help enhance the immersion of the experience?

For tracking the position of the brush, palette, and canvas in VR, the Vive tracker has been identified as the most optimal device. A Vive tracker is attached to a custom made brush, the second Vive tracker is attached on the palette, and the third is used for positioning the canvas.

For the brush pressure, a paintbrush head is attached to the custom brush to enhance the immersion of the experience. The Arduino Rev3 Uno, together with an FSR sensor, is attached to the brush deemed to be able to measure the brush pressure and send it over to the experience, visualizing the brush stroke thickness.

Sub-Question 3: Does the immersive 2D painting experience with the use of Playful Palette support the average users' painting skills?

The experience was positively valued by the participants. So were the interaction and interface of the experience intuitive and simple to use. Also were the brush and palette within this experience comfortable to use. In addition, the Playful Palette Color picker was mentioned to be very helpful as the desired colors were easily found. In sum, the immersive 2D painting experience supports the average users' paintings skills with the use of the Playful Palette.

Main Question: How do you develop an immersive 2D painting application that uses an intuitive interface with trackable painting equipment for traditional and digital artists in Virtual Reality?

The standard controllers were required to be replaced to enhance the immersion. To determine which hardware equipment was the most optimal, research was needed. Through the use of desk research and interviewing an expert of electronics, the optimal hardware for tracking was narrowed down to the Vive Trackers. For the brush functionality, the Arduino with the FSR sensor deemed the most optimal. Combining these two factors resulted in the trackable painting equipment.

For the intuitive interface, consulting a focus group of artists was required to determine the tools and functionality. By prototyping multiple iterations and through testing and evaluating using usability testing, the most intuitive approach to interact with the interface was narrowed down.

15 Discussion and Recommendations

First, addressing the elephant in the room, Covid-19. Did it had any effect on the intended tests or any of the results? Yes, due to Covid-19 specific tests such as the supportiveness test was put on hold until the last week before writing this report. That meant that there was only a small number of users could be arranged for the experience to test, the students at the lab. The results are also not significantly high due to the lack of users testing the experience because of the Covid-19 rules. While the original target groups are the traditional artist and the digital artist, only one traditional artist had tested the application. In addition to that, the client could only see the progress of the project through videos and images and only could try out the experience once it was returned to the lab.

Furthermore, the original focus group had to be dropped due to social distancing, allowing them not to visit and test the experience. As for the results considering the functionality and interactions, the original focus group mentioned several features that could have been implemented but had to be dropped due to lack of time. Moreover, a new focus group was assembled existing out of family members since most of the testing was done at home. Despite having the buttons resemble their respective functionality, one of the participants required assistants during the first usability test. The participant had barely any experience working with computer software, concluding that the user's experience does factor in when it comes to designing intuitive interfaces.

Despite that the test result indicated a favorable opinion of the Playful Palette color picker, it should be taken with a grain of salt due to the implementation lacking features the original Playful Palette does have. Besides, the implemented color picker took inspiration from the original color picker, meaning it is not the exact color picker.

When it came to hardware, the original plan was to test several sensors at the Crazy Lab at Saxion, due to the lab being closed this could not be done and the implementation of the hardware depended on other research studies conducted. Meaning that if the tests were done within this lab, other hardware equipment could have been chosen to replace the Vive controllers and replicate the brush functionality. While it was received as positive by the users, the use of the cable limited the users reach as more drag was applied by USB cable.

Therefore, a slimmer version of the brush can be developed. Instead of using an Arduino Uno Rev3, a mini Arduino could be used for this brush with a BlueTooth module attached to it, making the USB cable wiring to the computer obsolete. As well as soldering the wires together will allow the breadboard to become obsolete. However, this would require additional research for the future. The last recommendation for the hardware is to add tilt sensors in the brush, where it can recognize in which direction the paintbrush stroke is making, adding more immersion and visualization to the experience.

The current product only has basic functionalities and tools implemented. These tools can be expended on, such as adding more brushes. Watercolor, oil, and calligraphy brushes, as well as the different tips of brushes, can be implemented. However, additional research is required for this. Another functionality would be the save the actual progress of the experience instead of just saving and loading the painting. However, button mapping wise, the palette virtually only has a limited amount of room for these tools and functionalities. A recommendation would be to create an interface that allows various menus to be interacted with, allowing for more functionalities and tools to be added.

Another recommendation would be to add a QR scan so that others can see what kind of art is. The QR code would link to a separate local server and view the stored paintings there. For example, the lab could create a virtual museum where others can see the art and painting created within this experience.

While other the functionalities and interactions are implemented, the environment the users paint in is very bland looking and lifeless. A recommendation would be to assign a 3D artist student and develop furniture, plants, or anything relative to create a more comfortable

environment for users. While mentioning models, the painting equipment would need proper modelling as well. The current palette and brush used for the end product are not accurate to the palette and brush in the real world. Were the equipment more on point, it would have enhanced the immersion more. As for more visual feedback, specific effects should be implemented as well (e.g., changing the brush type changes the brush model.).

For the canvas, when drawing with a bigger sized brush or using the fill-in function, it takes a while if it needs to cover a more significant area. That is why it is the recommendation is to improve the way the paint is drawn on the canvas. By using Graphics.Blit, it will directly send it to the GPU saving time and performance instead of first going through the CPU. However, be wary of the HTC VR Headset, this already consumes a lot of the GPU when in use.

16 Product

The final product is a zipped video file that is a video demonstration of the VR Experience. In this video, the tools and functionality established through research are demonstrated, including the hardware equipment (trackable brush, palette, canvas and the Arduino with fsr).

The product is available through the following URL:

https://drive.google.com/file/d/1EkwEdCI0x44veh7TTZiN2i5M-NFWDnNx/view?usp=sharing

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18 Appendices

18.1 Appendix A. Expert Interview with Electronic Expert

Title: Expert Interview – Interactive electronics and trackable equipment interview

Date: 05-03-2020

Attendees

- Elias Elkhoury
- Harry Sanderink

Topics: Canvas, the pressure of the brush, detection sensors, pressure sensors, Infra-Red Sensor, Leap Motion. Gadget Control.

Details: The recorded interview is in Dutch; however, for continuity' sake of the thesis, the conversation has been translated into English. The primary purpose of this interview was to ask questions and brainstorm together to get as many possible options for the hardware equipment.

Question 1: How is it possible to detect the position of the brush on the canvas?

There are two objects to be concerned when it comes to the position of the brush in real life, the brush itself and the canvas. The canvas can be set up by having an infra-red (IR) detector on the sides, for example, using a Nintendo WII bar for that purpose. With an IR led attached to the brush, you can send a signal detecting the position.

Besides IR, it is possible to use an accelerometer and calculate which direction the brush is going so that you can get the position in VR.

Instead of a WII IR bar, it is also possible to set it up with an IR Leap Motion, Xbox Kinect camera, infra-red camera.

Thus, with these, you can detect the position of the brush.

Questions 2: Are there any restrictions or limits on these types of equipment?

Yes, there are always restrictions and limits. Once you do not point at the camera, it will lose the position, so you will not have a constant view of the brush in VR. Also, if someone walks before it or the camera gets blocked brush will not be tracked.

Question 3: Have you ever worked with something similar to this with VR?

No, no. I usually work with first and second years on these projects. I have worked with IR equipment and such alike before but nothing related to VR.

Question 4: For replicating the pressure of the brush, how can that be done?

That is possible with various sensors. Just to name a few from the top of my head:

the Bend sensor: When it bends, it sends a signal that it is, so when you get close to the canvas, you can then start drawing in VR. Theoretically, of course.

Flex sensor: It is the same as the Bend sensor but a short version.

What you could also use is the Distance sensor: When it gets close to the canvas, it will send a signal, and you can draw. However, you will need one on a short-range. I do believe there are a few of these kinds there.

It is also possible with magnetism; however, that is very challenging. So while I do mention it, I do not recommend it.

Question 5: What about the drawing with a curve?

That is possible with measuring the angles of the brush with a gyroscope. However, that approach can be quite challenging since you would have to consider that at each curve, various forces, and distances

Another possibility is with a tilt sensor. However, a tilt sensor works at a certain angle; if you want to do this for each perspective (360 degrees), that is not possible since there will be too many possibilities that the brush can be curved.

18.2 Appendix B. Focus Group for tools and functionalities

Title: Focus Group meeting/brainstorming

Date: 12-03-2020

Topic: Deciding the essential tools for the VR painting experience.

Group: A total of four artist students from the CMGT course, one graduate student, three SSS students.

Details: The primary purpose of this focus group was to brainstorm together to unanimously get the essential tools/functionalities for the painting experience that are doable.

The very basic functionality before Focus group:

1. Ability to draw
2. Ability to pick a color.
3. Ability to erase drawing (eraser)

Result:

The number of features will be at a minimum of a top-five since the main focus of the application is not only the functionality of the final product. Also, it should be a simple painting experience for everyone to use. So no need for excessive features. With the help of the MoSCoW approach, it was quickly determined which function had to come first. After each tool/feature, details were added as well as remarks by the artists.

To aid with generating ideas together, the group all tried the application at the time; they could easily see what was lacking and what was needed to make it easier to use.

Reference Photo: To be able to load in reference photo in the experience. It will become annoying to take off the headset and wear it again; just have a glance at the reference you are drawing. Having it directly in the experience would be a great and essential feature to have.

A new canvas: Instead of rebooting the application to start drawing again or erasing everything with an eraser, it is best just to be able to start with a new canvas but keep the experience running.

Ability to save and load: It just makes sense to be able to keep the painting you have made and load it back up if you want to continue painting on it. Or just, in general, to save it if you plan to paint something that might not turn out to be right. You can make mistakes, and instead of starting over entirely or have to erase the part carefully, you do not as you can quickly load the previous painting back up again.

Be able to adjust the brush sizes: A brush should be able to increase in size to cover more of the area you want to draw on.

Layers: Instead of painting one canvas and completely messing up the drawing, it is better to have multiple layers. This way, the quality of the painting is ensured, and the user can paint more comfortable with the feeling that if he/she makes a mistake, they will not have to start over completely.

Multiple Brushes: When it comes to painting, you usually have multiple brushes you use for different purposes. Just keep it at five to keep it simple since you would have to work on other tools as well. Consider adding a standard brush, a pencil for small and accurate painting, crayon, or spray for some gentle visual spray.

Fill-in: See paint bucket. More comfortable to fill in spots that can save up time when painting/drawing.

Ability to scale the canvas: The canvas is now at a fixed scaling. Being able to adjust the scaling of the canvas can help a lot with painting. Think of it this way, if a person would try the application, they might not want to start with a huge canvas. They might want to start small and maybe increase the size afterwards.

To cut and paste: It would be great to cut/slice off a certain part from the painting and move it somewhere else on the painting.

Undo/Redo: Instead of constantly saving and reloading the art if something went wrong, you could have a simple undo/redo button. That saves time as well as make it easier for the user.

18.3 Appendix C. Usability Test 1

This tablet contains the result from the usability test; under each participant, it will be written down if the task was successful or not added with small remarks on what they thought about it. Since all the participants are Dutch, the recording is in Dutch, that is why the following data has been translated to English. For most of the participants, it was the first time wearing a VR Headset.

	Participant 1	Participant 2	Participant 3	Participant 4	Participant 5
Age	22	25	18	58	56
Skill level	Traditional artist	Novice	Novice	Novice	Novice
Tasks to perform with their experience					
Drawing On Canvas	Successful "Wow, this is cool!, I can actually paint, with the brush attached it feels like I am drawing on a real painting."	Successful "Oh so if I press harder than it will become bigger? Brush feels nice even though it's big, it feels like I am really painting."	Successful "Oh that works nice but only from this corner… It doesn't seem to draw from each side properly…"	Successful "Oh, it feels like I am painting for real, I do need to make big swings, but that might due to the brush"	Successful "Yeah, it's good, look a flower"
Mixing Colors	**Pressed multiple times on the same color and by the end accidently changed colors** "Did I select blue right? Why did I get red? Why aren't the selected colors showing? Color mix is beautiful! I love this shade of purple though"	**Pressed multiple times on the same color** "Did I get the color? Where can I see if I have selected the color? Wow the mixing colors are so pretty!"	**Pressed multiple times on the same color to be sure they had selected the right color.** "Uuhmm.. Why isn't it saying I pressed a button? Did I not press it? These colors are cool though!"	**Successful but lacking visual feedback** "I am having issues with picking the colors, it doesn't tell if I have selected a color and if the selected color is the color I wanted. I wanted blue I got green?"	**Successful but lacking visual feedback but due to their understanding they only pressed once and it worked** "Oh look.. pretty.."
Picking Mixed Color	**Did select the color but there was no visual feedback** "Did it work? Where is my purple?"	**Managed to select the color, however due to lacking visuals kept repeating the same interactions**	**Successful but doubted themselves due to lack of visual feedback** "That's it right…? I can	**Successful but due to lack of visual feedback the participant doubted themselves**	**Successful but due to their understanding they assumed it worked and continued to draw**

	"Oh! When I draw I can see it.. Hhmm.. Maybe you should change the brush color?"	"I really like the color combinations I can create, but I am not sure if I picked the color I wanted where can I see that?"	just draw now? Or did it not select it? Where can I see it? I thought the brush would change color since it is black and the starting color is also black."	"It's not clear if I selected the color.. Should I do it again just to be sure?"	"Okay.. So I can draw now.. Ah that's a beautiful color"
Saving Image	**Successful but lacking visual feedback caused the participant to doubt and resulting in multiple presses.** "Did I even save? Where can see that?"	**Successful but lacking visual feedback causing the participant to doubt.** **Long pause** "…is it saved..?".	**Successful but lacking visual feedback which caused the participant to doubt.** "Uhm.. It saved right?"	**Successful but lacking visual feedback caused the participant to doubt and resulting in multiple presses.** "Am I done? Is it saved? I am going to press it a few more times to be sure"	**Successful but lacking visual feedback caused the participant to doubt** "Did I do it?" "Should it say saved or something?"
Add a new Layer	**Successful but lacking visual feedback resulting in multiple presses.** "Should I stop? I cant see if it worked so I will just press it a few more times… Okay Oh layer 14.. That's too much isn't it?"	**Successful but lacking visual feedback resulting in multiple presses.** ""Same with the save button, I am not sure if I did it or not Oh I can see it above the canvas with the name"	**Successful but lacking visual feedback resulting in multiple presses.** "Yeaahh.. That works but I am not seeing it happen on the palette though. Now I have 7 (layers)."	**Successful but lacking visual feedback resulting in multiple presses.** "Did it work? It doesn't say if I did it or not.. where should I see it happen?"	**Successful but lacking visual feedback made the participant doubt** "I am not sure if I did it or not, should I press it again?" **Pressed multiple times to be sure**
Start a New Canvas	**Successful but lacking visual feedback** "Oh.. well.. I expected a warning or	**Successful but lacking visual feedback** "..Should I save before	**Successful but lacking visual feedback** "Oh.. It worked.. But yeah I would	**Successful but lacking visual feedback** "Oh, hmm.. same with the other	**Unsuccessful, pressed wrong button the first time. After a second**

	something like "Do you wish to save the painting?" kind of option before starting a new file. Also.. no visual feedback"	that? Or does it save automatically? Also, it wasn't clear if it worked until I looked at the canvas"	like to see it happen where I am looking at, not when I turn to the canvas… Besides that, a pop up for saving would be nice… "	buttons, they don't show I pressed them or not."	**attempt successful.** "I thought the wipe was for wiping the canvas clean, next time I know"
Select Fill-in/Crayon/Brush/Pencil tool	**Successful** "Oh! Nice they pop out of the cup!" "Ah, so that's the brush, crayon, pencil and bucket, right?"	**Successful** "oh that's kinda cool"	**Successful** "Ah.. that's cool, crayon right? Yeah that's clear to see."	**Successful** "Oh.. now that's nice, why don't the other buttons do that?"	**Successful** "Oh haha, that's funny"
Change the Brush Size	**Successful but the same interaction happened before they could move their brush** "Oops.. I didn't do that did I? I just wanted to press once"	**Successful but button repeated the interaction** "It's not supposed to do that right? Or do I need to be carefully pressing this button?"	**Successful but button repeated Interaction** "…What just happened…? Was it supposed to do that?"	**Successful Same interaction happened but was not noticed by the participant**	**Successful Same interaction happened but was not noticed by the participant**
Loading Image	**Could not load the image due to small interface Not clear which file they had selected.** "How am I supposed to press these buttons? Did I even select the right file?"	**Took multiple times with careful precision to load image.** "Oh wait.. which button do I need to press to load? Why is it so sma- Did I just close the window?"	**Loaded the image with a lot of effort.** "…Did I select the file? Where do I see t- Oh down there, that's not clear. Why are the buttons so small?"	**Failed to load the image by pressing the other button due to size.** "I am pressing the right button? No? They are really small. Did I even select the file?"	**Gave up after trying multiple times. Buttons too small to interact with.**

18.4 Appendix D. Usability Test 2

The changes made for the interface were based on the feedback given during the first Usability Test. For the second Usability Test, the same participants took part. Once more, their behavior, feedback and interaction with the interface were documented. For this usability test, the load, save, new canvas, new layer, delete layer, and clear palette buttons had all been given an indicator that they were successful with interacting. The sizes of the buttons were changes as well for the load window. A small interaction timer was implemented to prevent users from interacting with the same button again before the function had been executed. When a color is selected from the mix, the brush will change color accordingly, given a clear indication that the color has been chosen. The goal of this test was to see if the adjustments made were better than last time and if there were any further improvements required.

	Participant 1	**Participant 2**	**Participant 3**	**Participant 4**	**Participant 5**
Age	22	25	18	58	56
Skill level	Traditional artist	Novice	Novice	Novice	Novice
Tasks to perform with their experience					
Mixing Colors	**Successful, tried different color combination to see what is possible** "Yes, that's so much better, now I am sure which color I am picking."	**Successful** "Why didn't you do this the first time? This is so much better."	**Successful, tried multiple times to see what other selection was possible.** "Ah, that's way better. Maybe change the color of the circle as well?"	**Successful, tried other colors to see** "Yeah, this is much better and clearer than before."	**Successful** "Oh that didn't happen last time did it? Hmm.. Oh it does help, now I know which color I have picked."
Picking Mixed Color	**Successful, tried multiple times to see how the brush changed.** "See, that is what I was talking about, clearly visualizing the color you picked with the brush."	**Successful, tried multiple times to see how the brush changed.** "That's clear changing the brush color, now I can see which color I have selected instantly.."	**Successful tried multiple times to see how the brush changed.** "Ah that's a lot better, that's indeed the color I wanted. What about the color I wanted before though?"	**Successful** "Ah, the brush changed color, last time I had to rely on that square this is a lot better."	**Successful** "Okay.. So I can draw now.. Ah that's a beautiful color"
Saving Image	**Successful**	**Successful**	**Successful**	**Successful**	**Successful**

	"Ah, it gave a small check mark so that means it worked right?"	"Way better, with the check mark"	"Yup, that's clear. It saved."	"Ah okay, it saved, last time it didn't do that, right? Way better."	"Oh.. it saved. How can I tell? By the green check mark right?"
Add a new Layer	**Successful** "Ah, same with the save button. A lot better,"	**Successful** "Ah, yeah way better, good!"	**Successful** "Cool, same with the save button, does that also work with the other buttons?"	**Successful** "Ah, okay clear, created a new layer, now I can draw right?"	**Successful** "Oh, the checkmark again, so it worked right? Oh I can see the name changed of the canvas so it worked."
Start a New Canvas	**Successful** "Ah, yeah this is better, with the pop up window for asking to save or not. Good!"	**Successful** "..Should I save like last time? OH, it asks to do that before you start a new canvas. That's awesome! Also the check mark, I can assume you did that for every button?"	**Successful** "It works, and I can save the painting if I like… But what if I want to cancel? Wouldn't that also not be a thing?"	**Successful** "Ah okay so I can save again… I will not.. So just like with the other buttons the green checkmark. That's good.."	**Successful.** "I got it this time, maybe if they were not so close together others will not make the same mistake?"
Change the Brush Size	**Successful but found the interaction timer too slow.** "Hmm.. It works and it doesn't do the same thing like last time but it takes a bit too long before I can press it again"	**Successful but found the interaction timer too slow.** "Works, takes a bit too long before I can press it again, I thought for second the max was x2"	**Successful but found the interaction timer too slow.** "…Way better but do I really have to wait this long before pressing again? Can you make it shorter?"	**Successful did not notice a difference between their first time using**	**Successful did not notice a difference between their first time using.**

Loading Image	**Successful** "Way better, and easier to look at. Buttons are bigger and easier to press. I can now see which file I have selected so that's good."	**Successful** "What.. This is totally different from last time, it's way better. Buttons are bigger, I can scroll, the window doesn't look so boring. File selection works.."	**Successful but canceled first to see if that button also worked.** "Nice, this is way better than last time, also less edgy(dark of color). Buttons are clear, file selection works, here I can cancel as well.. Okay that works, cool"	**Successful** "Ah it's all so clear now, buttons are bigger, file selection works, I can scroll and loaded."	**Successful** "I could not do this the last time I tried.. So much better."

18.5 Appendix E. Usability Test 3

The changes made for the interface were based on the feedback given during the second Usability Test. For the third Usability Test, two of the five participants took part. Three others were asked from the lab. Once more, their behavior, feedback and interaction with the interface were documented. For this usability test, the additional option for asking if the user is left-handed or right-handed at the start was implemented. The interaction timer had been shortened to speed up the interactions between buttons. The mapping of the buttons and color picker had to change due to adding a left-handed and right-handed version of the palette. The color picker now has a history implemented so users can select their pervious color again. The goal of this test is to determine if the new stored color implementation works and if the interaction time should be shortened further.

	Old Participant 1	Old Participant 2	New Participant 3	New Participant 4	New Participant 5
Age	22	18	22	22	22
Skill level	Traditional artist	Novice	Novice	Novice	Novice
Tasks to perform with their experience					
Selecting left or right hand	**Successful** "Ah finally, now I can use my left hand."	**Successful**	**Successful** "Oh so I have to pick if I am left or right handed? That's cool"	**Successful** "Ah, I am right handed so yeah."	**Successful** "Oh this is very clear, left or right. Got it. Right"
Pick Stored Color	**Successful** "Oh I can even see what colors I used to get this color, that's cool! Oh but I did lose my previous color combination? Ah."	**Successful** "Ah that's what I wanted last time, nice! Oh, so if you pick a color again you can even add it to the new selection? That's cool"	**Successful** "Ah so I can see what colors I have selected previously and which colors were combined to get that result. Nice, nice. "	**Successful** "Wow, it's really amazing looking back at the different color combination I have made. It is also possible to continue from the selected choice?"	**Successful** "Ah so when I pick a color it gets added to the side… Got it. That's a cool feature."
Change the Brush Size	**Successful** "Ah, the time between pressing buttons is a lot better than last time"	**Successful** "Nice, the wait time for the buttons to be pressed again is a lot better"	**Successful** "Okay, it works.. Nice Ah you even gray it out when you reach max. Good."	**Successful** "Clear, and it works fine"	**Successful** "Works"
Additional comments:	Buttons were clear, adding a history for the color picker was a very	Everything was clear, adding left and right handed	The buttons are clear. The feedback I received was clear.	The mapping of the buttons are clear, feedback is visual	Adding the left and right handed question at the start

	good feature. I like that the palette can also be used by left handed people, since I am left handed as well.	question at the start was a good addition. I really liked that I was able to choose the last color I picked again	I really love the color picker when I move around with the color blobs. The fact that users get asked before they start if they are left or right handed is a very nice feature. The fact that you were able to replace the controllers with a trackable brush and palette is really well done.	pleasant. I like the color picker a lot. Adding the option if the user is left or right handed makes the application usable for everyone.	makes the experience applicable for everyone. The fact that you don't use any of the controllers but are actually painting helped really well with the immersion.

18.6 Appendix F. Questionnaire

Playful Painting Questionnaire

*Vereist

How did the interaction and interface feel within this experience? *

1 2 3 4 5 6 7

Unintuitive and not easy to use   ○○○○○○○   Very intuitive, extremely easy to use

How did you experience the usage of the brush and palette? *

1 2 3 4 5 6 7

No, I was extermely uncomfortable with the equipment   ○○○○○○○   Yes, I was extermely comfortable with the equipment

Did the use of the Playful Palette color picker make color choices easier? *

1   2   3   4   5   6   7

No, not at all   ○ ○ ○ ○ ○ ○ ○   Yes, finding the right color was extremely easy

If you could rate your overall experience, what would it be? *

1   2   3   4   5   6   7

No fun at all   ○ ○ ○ ○ ○ ○ ○   Excellent, I want to try it again!

18.7 Appendix G. Reflection
Name: Elias Elkhoury

Student Number: 324920

Company: Saxion's XR Lab, Enschede, The Netherlands

The Reflection is based on the twelve Competences of the CMGT Graduation Manual.

I Technological Competences

1. Technical Research & Analysis

The entire purpose of this research assignment was to develop a 2D immersive painting application in VR. While I had the foundational knowledge of working in Unity and start developing the basic setup of the experience, additional knowledge was required to realize the concept idea of the client.

Therefore, thorough research was done to gather the required knowledge about the best way of implementing the Playful Palette Color Picker. Develop the replaceable hardware equipment (The custom made brush, palette and canvas), with the use of an Arduino, FSR sensor and Vive Trackers, which I have never worked with before. Which in the end, resulted in a stable and working prototype.

2. Design & Prototyping

Design choices were made based on the feedback from the users. The feedback was given after the users have tried an iteration of the prototype. After that, the prototype would go under development again, creating a new iteration to be tested. On a (bi)-weekly basis, the client would get feedback from the developer, which in return, the client would give feedback back. The given feedback would also be taken into consideration and implemented in the further design choice for the prototype.

3. Testing & Rolling Out

The usability testing model of Nielsen and Landauer (1993) was the preferred testing method to use to gain as much feedback as possible with a little number of users and sufficient time. However, due to the Covid-19 lockdown, these tests were not conducted with the intended target group but with family members. Luckily, one of the participants is a traditional artist, so their input and feedback were applicable, especially since they were the first user for every test to observe and learn from the most. Despite the others not being artists, their feedback and input turned out to be very beneficial and led to the development of the current interface of the experience.

Another example would be the Playful Palette color picker, while the authors do mention that the Playful Palette is developed by implementing a variant of the metaball. Metaballs are quite expensive performance-wise, and with the use of VR, the available performance is limited. Therefore, additional tests were required to compare which metaball method was better applicable for using in this experience.

II Designing Competences

4. Investigating & Analyzing

With the use of the CMD Methods (Interview with Expert, Questionnaire, Best, Good & bad practices, user testing, usability testing, focus group and brainstorming), obtaining valuable knowledge was possible. With the acquired knowledge, issues could be resolved, and new ideas could be conceptualized to be developed. For example, because the Crazy lab was closed, further research was required to analyze the right hardware to be used for replacing the Vive Controllers. With the acquired knowledge from the interview with the expert of electronics. I was capable, with the use of "the best, good & bad practices" method, to

compare the most recent conducted research study results about these electronics and find the most optimal one to implement.

5. Conceptualizing

For the concept of the functionality and tools of the interface, I had to gain some basic knowledge of what should be an essential functionality or tool to have. Therefore, a focus group was gathered together to brainstorm about possibilities. With the obtained knowledge and additional testing to determine the recognizability of the buttons, the tools and functions could start their development in the experience. The client seemed to like the additional features such as the capability of adding layers, multiple brushes and saving and loading color dishes. For the concept of the brush, several materials that could be potentially used were gathered together. Different combinations were thought of before landing on the final concept for the brush.

6. Designing

Everything set out during the conceptualizing phase had been worked out, and the design of it was finalized. For example, the interface, through various testing of the interface's intuitiveness, the final design for it was found. For the brush, to create a stable and balanced brush (since the Arduino and Vive tracker are attached at the back), the front of the brush has a metal cylinder attached so that the weight balances out. The brush itself is on the robust side despite that the client was pleased with how the brush felt and looked.

III Organizational Competences

7. Enterprising Attitude

When researching for hardware, I kept in mind that the financial range should be feasible, meaning that equipment should not be bought without consulting the client. A list of electronics was put together with the use of the research results. The client would be asked if he agreed with the items on the list so that they can be bought.

8. Enterprising Skills

The essential goal of this project is to be a demonstrator for the XR Lab. While it will not be sold (maybe in the future), the use of this project is to obtain more clients for the client. So when the client has clients, he can use this project to demonstrate what the lab and her students are capable. That is why certain decisions, such as the interface, was tested with not only artists but with none artistic users as well.

9. Working in a project-based way

The minimal viable product had to be realized at the end of the semester, that is why the project had to be executed iteratively and systematically. Through this method, feedback could be received as soon as possible and create a new iteration of the prototype. This lead to multiple tests and iterations where design choices were validated and used to continue further development.

10. Communication

During meetings with the client, I would showcase the progress made. Either during the call or sending a video beforehand. However, this was not always the case, which is brought up by the client as well. Most of the time, I would talk about progress but not show visual content. Even if it was not working at the time, the client would have liked to see the progression. This is something I will have to work on for the future, to accept the fact that progress is progress, even if it is not fully working. It is better to showcase what is there than to showcase nothing at all. However, when showing the results, the client was pleased with the progress made. The report is written in a business-like matter that gets the point. Illustrations are used to address the topic that is spoken of in the report.

IV Professional Competences

11. Learning ability and reflectivity

In early development, I would have already have dug myself several holes if it was not for the weekly guidance and feedback of my client. I learned that there are more possibilities, and sometimes it is better to start simple and improve further from that point. I also learned that it is okay to ask for help. This is still something I need to work on despite that I still managed to request assistance from other students or teachers with expert knowledge of a specific topic. As a result, the issues or knowledge gap I would have got resolved. Knowledge to gain that would have taken days got filled up within hours. The obtained knowledge could sometimes be used to fix other issues as well.

12. Responsibility

Due to the Covid-19 lockdown, the whole prototype development was done from home. During this time, the only way to contact the client was by mail and video calls. Weekly, there would be a meeting with the client to discuss the progress. Besides that everything was on the developer. To make sure the client's expectations were met at the end of the lockdown/graduation phase. I took the responsibility to conduct multiple tests to gather reliable feedback and validate the choices made for developing the features. Applying methods from the CMD to ensure the research was thorough and did not leave any possible option unturned. This all was done for the goal of delivering a functional prototype for the client. Also, taking care of the loaned equipment (VR headset and computer) at home.