Bachelor Thesis

Developing an Interactive Art Exhibition in Social Virtual Reality

Maximilian Hauschild

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Supervisor: Dr. Shenghui Wang

Critical Observer: Dr. Ir. Robby van Delden

Creative Technology

University of Twente

Faculty of Electrical Engineering, Mathematics and Computer Science

Abstract

Art and history museums provide valuable education for everybody. However, young people are unintentionally excluded from these exhibitions because of the modalities surrounding the visit to such museums. As traditional museums offer exhibitions without components of interactivity and enforce social norms that prohibit unobstructed social interactions, young people tend to stay away. Additionally, young people spend more and more of their time in the digital and online world. To provide a more appealing way for young people to visit art and history exhibitions, this research project proposes an interactive social virtual reality exhibition.

The developed interactive experience allows multiple users to experience the art exhibition "HERE: Black in Rembrandt's Time" together with another person they know. In the virtual version of the exhibition, visitors can pick up three-dimensional models of objects in the paintings. The objects are connected to a quiz interaction that can be triggered by returning the object, allowing visitors to further educate themselves about the topic of the exhibition by completing the quiz questions and reading the subsequent additional information. Users can fully immerse themselves in the virtual exhibition using a head-mounted virtual reality display. Additionally, users are represented in the virtual world using an avatar that resembles their bodily features for higher immersion.

To evaluate the interactive experience on user engagement, testing was conducted with a total sample size of 20 participants. To test the impact of the social components, one group of 10 participants tested the experience alone while the other half of the participants tested the experience in pairs. The evaluation was done by using a set of questionnaires and by conducting individual interviews with the participants. Furthermore, the observations made during testing were analysed.

The research concludes that the application of virtual reality museums for art exhibitions can increase engagement among young visitors. The addition of a social experience in virtual reality may increase engagement, however, statistically reliable evidence could not be found. Additionally, social interactions appear to help with the understanding of the cultural contents of art exhibitions.

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List of Abbreviations

Virtual reality - VR
Social virtual reality - SVR
RQ - Research Question
Head-mounted display - HMD
User interface - UI

Chapter 1: Introduction

1.1 Context

The museum is a place of education for everybody. Unfortunately, they often cannot offer an appealing experience for their younger visitors. This is especially true for art and history museums, which leads to an unintentional exclusion of their younger audience. [1] . To make museums more attractive to a younger audience and improve their level of education, the implementation of interactive and immersive exhibitions can be advisable [2].

One way of bringing interaction to exhibitions is by using virtual reality (VR), a technology that allows users to engage in interactive experiences in fully immersive virtual environments that are not subject to physical limitations like in the real world. Paired with currently available platforms for social virtual reality (SVR), multiple users can visit such an interactive exhibition at the same time, sharing the same virtual space independent of their actual location. This can further help museums to make their educational offers more accessible to the young generation who spend their time increasingly in the digital space [3].

1.2 Problem Statement

The goal of this project is to create an interactive experience for the art exhibition „HERE: Black in Rembrandt's Time“ in social virtual reality (SVR), using the platform NeosVR. The exhibition aims to educate visitors about the representation of people of colour living in the Netherlands during the 17th century. The curators of the exhibition, which has been presented at the Rembrandthuis Museum in Amsterdam, specifically want visitors to see that many people of colour lived in the Netherlands as free and sometimes wealthy members of society, which at the time was also reflected in the art they were portrayed in. The interactive experience must convey the intentions of the original curators and must serve as an aid for the visitors to achieve a better understanding of the story of the presented cultural heritage.

To achieve this, the interactive experience should feature rich interactions in a compelling environment to allow for an immersive and engaging experience for multiple visitors. The provided interactions should also leverage the unique possibilities provided by the social VR environment. This entails enabling cooperation and communication between visitors to benefit the educational aspect as well as increase visitor engagement.

Methods of interactions suitable for this scenario have to be founded in previous research done on virtual reality. Due to the novelty of social VR as a sub-topic of virtual reality and the subsequent lack of scientific material, a combination of successfully tested and promising interventions of existing VR exhibitions for museums should be used as the foundation for this new social VR experience.

Finally, the new design needs to be tested with young adults as representative test users to analyse its impact on their engagement and learning experience.

1.3 Research Questions

During the research on this project, the following questions shall be answered:

Primary RQ: To what extent can social virtual reality exhibitions improve engagement among young museum visitors?

Sub-RQ 1: What is the impact of interactions with elements of gamification on user engagement in virtual reality?

Sub-RQ 2: How can a multi-user experience improve the understanding of cultural heritage topics in an art exhibition in SVR?

1.4 Thesis Structure

This thesis is structured into 9 chapters that describe the different phases of the research. After this introduction, the background research on the matter will be explained and the current state of the art will be exposed. Chapter 3 includes the general methodology of the entire design process as well as the specific approach for each design phase. Chapter 4 describes the ideation of concepts based on stakeholder needs and findings from Chapter 2. Additionally, the chapter will discuss the final concepts that emerged from the ideation process in detail.

Chapter 5 illustrates the definition of specific requirements for the realisation of the prototype that is described in Chapter 6. The process of its evaluation, entailing user testing and data analysis of interview and questionnaire data will be described in the following Chapter 7. Further, in Chapter 8 the outcome of the evaluation will be discussed and recommendations for future research will be outlined. In the final chapter, conclusions regarding the research questions will be stated to conclude the report.

Chapter 2: Background

2.1 Literature Review

A review of the literature was conducted to gain general insights into the topic of museums in virtual reality. In this section, related research will be discussed in the context of their findings on the permissibility of VR in museums and findings on ways to create engagement. In particular, the ways in which virtual reality can be applied in educational settings, the concept of engagement in connection with VR and finally interactions in social virtual reality.

2.1.1 Introduction

Museums have been a great way to enable the broad public to educate themselves for centuries. However, with the changes brought to media and education by the digital age, museums are also looking to adapt to new ways of presenting information. One way of achieving this is by using new technologies such as virtual reality to make exhibitions more interactive. Despite being predominantly known as a platform for entertainment, virtual reality has the potential to make a positive impact in many fields of education [4]. Among other benefits, the novelty of the technology draws attention and can improve engagement, which can be a good reason for museums to explore it. VR can also facilitate remote multi-user experiences for exhibitions, allowing multiple visitors to have natural and social interactions from anywhere. This is commonly referred to as Social Virtual Reality (SVR).

There are many ways in which museum exhibitions can be brought to VR, but not all of them are ideal to help with the educational mission of the museum or to improve the engagement of its visitors. Therefore, the goal of this literature review is to give insight into how visitor engagement can be improved through the use of social and interactive virtual reality exhibitions for art museums.

This review of the literature consists of three parts, with the first focusing on how virtual reality can have a positive impact in an educational setting, the second aiming to define engagement in virtual reality and the final one providing insight into interactions in social virtual reality. The last section focuses on interactions that might be suitable to increase engagement among young visitors.

2.1.2 Virtual Reality in Education

On a general level, virtual reality can provide certain advantages in education when compared to traditional methods. A review of the literature conducted by Pirker et al. [7] shows that the main advantages lie in the areas of immersion, visualisation, opportunities for playful design as well as social experiences. However, the literature suggests that the type of educational setting seems to have an impact on the effectiveness of VR.

Two major distinctions can be made regarding the setting in which VR finds usage: Educational settings can be formal or they can be informal, also referred to as casual. While formal educational settings refer to settings such as classrooms and schools in general, museums offer education in a more casual setting. According to Mystakidis [1], formal education is a highly relevant setting for the educational use of VR, because students generally follow the teacher's instructions while benefiting from the potential of VR to deliver a more enjoyable learning experience. Backing this up, virtual worlds were generally found to facilitate a more effective and engaging learning process, regardless of the use of VR [9].

On the side of casual settings, of which a museum is one, the findings regarding the use of VR were inconclusive. While Hayes and Yoo [3] argue in favour of the great potential of VR in a more relaxed setting, Rehnberg et al. [4] see the pitfall of this setting in the diverse set of users. According to them, it prohibits the use of complex interactions and control inputs because of the differences in technological proficiency. This discovery is also described in the review by Pirker et al. who suggest using simple controls to reduce insecurity [7]. This negatively impacts the experience, since a high level of interactivity is shown to be a crucial component of an engaging experience [2, 3, 4]. Further demonstrating this conflict, Tsita et al. [8] generally see the benefit of VR in a museum in the possibilities to enhance the educational value of exhibitions by implementing interactions that cannot be facilitated in a physical exhibition.

It was discovered that it is currently difficult to create truly accessible VR exhibitions for a museum. This is because even the awkwardness of wearing a head-mounted display (HMD) but also because the perceived personal lack of technological proficiency can deter potential users [2]. While not reporting any of those issues, Hayes and Yoo [3] found a major potential of VR in a museum to be the helpfulness in the archiving effort of any museum. The combined findings show that there are generally more potential uses for VR in museums than just the educational aspect in itself, but accessibility and usability concerns must be addressed in order to create experiences that can be engaging for most users.

Apart from concerns about the differences in settings, there are also a variety of effects of VR mentioned in the literature. Researchers agree that the use of virtual reality in education can facilitate high levels of immersion and presence, leading to an engaging and true-to-life experience [1, 2, 3, 5]. This common ground among scientists shows that the general application of VR in education can have a positive impact on learners. Despite seeing the mentioned positive aspects as well as a higher level of general accessibility to special collections, Zhou also mentions that VR exhibitions can also have negative effects [2]. These include the loss of authenticity due to the digitalisation of a real artefact as well as the diversion of the visitor's attention away from the exhibition towards the technical spectacle of virtual reality [2].

These potentially negative effects can however be mitigated by design, which leads to the overall positive conclusion that VR can facilitate user experiences with a variety of positive effects.

2.1.3 Engagement in Virtual Reality

Before reviewing the factors that contribute to user engagement, the concept of engagement itself needs to be defined in the context of this project. Engagement can be defined in a plethora of ways, however each with a different focus. For the work carried out in this design project, two established definitions apply most. In their in-depth analysis of the topic, Doherty and Doherty [15] quote the definition by Sidner et al. [16] which reads:

> *"By engagement, we mean the process by which two (or more) participants establish, maintain and end their perceived connection. This process includes: initial contact, negotiating a collaboration, checking that other is still taking part in the interaction, evaluating whether to stay involved, and deciding when to end the connection."*

This definition is particularly applicable to this project, as the goal is to develop a social experience in virtual reality. However, there are more components to the concept of engagement than the ones mentioned above, as those are purely related to social behaviours and interactions. For this reason, the more general definition by Dobrian et al. [17] will also be used as a framework to define engagement going forward. They define engagement as follows:

"Qualitatively, engagement is a reflection of user involvement and interaction."

Dobrian et al. relate engagement directly to the interaction and involvement of the users. This train of thought is reflected in the further analysis of Doherty and Doherty, who list involvement as part of the factor of immersion as a contributor to engagement [15]. Also in support of this approach, Maloney et al. [6] report that the levels of immersion and interactivity are crucial factors for engagement in VR. In more detail, according to Zhou [2], immersive and interactive environments allow the users to spend time exploring the virtual scene, resulting in higher engagement.

According to the extensive review and analysis of Doherty and Doherty, nine design strategies facilitate engagement [15]. Immersion, as mentioned before, is defined as its own category of design strategies to facilitate engagement. Interactivity, however, is rather mentioned as a more general component of interaction, but in particular interactions with the virtual world can be understood as a part of the category "Inspiring Fun" [15]. In more detail, gamified interactivity plays a role in facilitating engagement. Mystakidis's [1] case study on student engagement in VR illustrates how gamified elements elicited students' engagement in the form of higher interest, motivation and autonomy while learning about a new topic. This is also backed up by a literature review on the general effectiveness of gamification, which shows that gamification in education yields largely positive results in terms of motivation, engagement and enjoyment of learning tasks [10].

Another way to approach engagement from the perspective of interactivity is to facilitate exploration within the game world [15]. This design strategy, defined by Doherty and Doherty, is also employed by Hayes and Yoo [3]. Apart from immersion and interactivity, the concepts presented in the definition by Sidner et al. can also be found in the body of literature that has been reviewed. The study conducted by Maloney et al. [6] suggests that a major reason for their teenage participants to use VR is to connect with others in social settings rather than looking for entertainment or educational content per se. In support of the relevance of social interactivity when thinking about factors for engagement in VR, Zhou [2] noted that the possibility to interact with others naturally can increase the overall engagement with the exhibition by allowing visitors to collectively interact with the exhibits. Moreover, both Zhou [2] and Mystakidis [1] mention the benefits of creating a sense of presence by using social interactions and avatars in VR to further increase immersion and therefore engagement.

More factors facilitating engagement are listed by Doherty and Doherty, however, based on the reviewed literature the areas with the highest impact seem to be interactivity in the form of gamification, possibility for exploration, social interactions and most importantly immersion. Still, the other factors listed also appear in the body of the reviewed literature. For example, ensuring usability and managing user resources, two concepts closely related, are also present in the literature. Rehnberg

et al [4] mention this as a pitfall of VR since diverse sets of users can lead to usability concerns. Similarly, managing user resources, which mainly entails the cognitive load and challenge of an interactive experience, is listed as a design strategy to facilitate engagement. Further backing up the accompanying concern about creating cognitive overload, Pirker et al. recommend reducing the complexity of control inputs to avoid this adverse effect [7].

While three additional factors are defined by Doherty and Doherty, namely enabling flow and replayability as well as emotional connectedness, the previous six appear to be most applicable for the later phases of this project.

To conclude, the concept of engagement can be defined as the reflection of the user's involvement and interaction as well as their social connectedness among one another. While this definition is not the exclusively correct one for the concept, it is the most applicable way to define it for this project.

Furthermore, the literature backs up the claims by Doherty and Doherty that social interactions do have an impact on engagement, while, however, the main driving forces of engagement in VR are the unique possibilities to create immersion and interaction through gamification and exploration of the virtual environment.

2.1.4 Interactions in Social Virtual Reality

On the topic of specific types of interactions, the literature shows that basic interactions are generally preferred for a diverse audience, but can be accomplished in a variety of ways. Demonstrating this, Maloney et al [6] state that the teenagers participating in their study predominantly enjoyed the possibilities of exploration but also crafting as a form of interaction in a social virtual world. Similarly, Zhou [2] indicates that explorative interactivity works well in the context of a virtual art museum. Despite not involving a social component in their study, this may serve as a further indicator that explorative interactivity may be beneficial to user engagement in the combined situation of social VR in an art museum. Further backing this up, Rehnberg et al [4] underline that simple interactions, which exploration can be classified as, generally work best for visitors of a museum.

Another discovery concerning usability for a diverse set of users was made in the study conducted by Selmanović et al. [5]. Their study demonstrates that experiences involving interactions with diegetic elements in the virtual environment have a positive impact on the perceived ease of use.

Finally, the paper on VR interactivity by Hayes and Yoo [3] describes that their approach of facilitating simple interactions through static hotspots with 360˚content yielded positive results as well. The latter two findings show that there are many options for interactions to be explored concerning their actual effectiveness for a diverse audience. However, more limited interactions such as the static hotspots proposed by Hayes and Yoo [3] may come at the price of lost value in the overall experience.

To conclude, there is no certainty in the literature about the type of interactions that truly work best for all users. Further avenues need to be explored to find the ideal balance between simplicity and complexity in interactions for virtual exhibitions.

With a field as novel as social virtual reality, it comes as no surprise that not only the types of interactions but also the preferred multi-user setup are still the subject of ongoing research. Still, one of the key discoveries in the current research seems to be the importance of presence as well as co-presence in social VR.

Presence is described by Mystakidis [1] as ”the sense of being in a space“, while co-presence refers to the acknowledgement of the real person behind a virtual avatar. His research suggests that these two concepts are important factors in the success of an experience in social VR. Affirming this, Zhou [2] also mentions that a social environment facilitating high levels of presence and co-presence can create meaningful experiences through more natural social interactions.

Building on this hypothesis, Drey et al. [12] propose that a symmetric setup for pair-learning situations in VR should be employed to achieve high levels of presence for both participants. A symmetrical setup entails that both users engage in the virtual world using the same device, e.g. a head-mounted display. A similar note was made by Mystakidis [1] who describes that meeting synchronously in VR with avatars can facilitate the experience of co-presence.

On a slightly contrary note to the latter, the results of Latoschik et al. [11] indicate no statistical difference in presence based on avatar appearance. This is however limited since their research focused on the more nuanced difference between realistic, 3D scanned avatars and avatars with the appearance of a wooden puppet.

To summarise, researchers agree that presence and co-presence are critical concepts that define the fidelity of any social VR experience and therefore need to be addressed when designing them. For the context of an exhibition in a museum, especially the discoveries regarding the impact of symmetric systems and avatars lead to new questions for further research and design endeavours.

2.1.5 Conclusion and Discussion

The goal of this review was to get more insights into how visitor engagement in art museums can be improved through the use of social and interactive virtual reality exhibitions.

The reviewed literature allows for the following conclusions to be derived: Employing virtual reality exhibitions in museums can facilitate uniquely immersive and engaging learning experiences. High levels of visitor engagement in VR can be facilitated by providing an immersive and interactive experience, with interactions that are of social as well as game-like nature. Interactions with the virtual world should provide a level of complexity that allows for interesting experiences without overwhelming non-technical users with difficult control schemes. In multi-user settings, all users should be provided with the same type of device as well as an avatar to achieve high levels of presence, which influences engagement.

Despite this positive outlook on the topic, caveats exist. The characteristics of interactions need further exploration, and balancing engaging interactions with usability remains a problem for current designs in the reviewed research projects.

The museum itself, as literature suggests, is an institution for which virtual reality experiences can generally have a positive impact. Both on the experience of the visitors as well as the actual educational mission of any museum. However, the diversity in visitors concerning their technological proficiency limits the possibilities for interaction in virtual experiences, making this the

aforementioned major issue with such projects. Additionally, accessibility for the physically, visually or mentally impaired, which is a topic managers of museums have a special focus on, is difficult to facilitate compared to settings with less uncertainty regarding individual user requirements. Another problem with virtual exhibitions in museums is the proper representation of historical and cultural artefacts. This has not been sufficiently addressed in the reviewed literature, but must not be overlooked during the development of a virtual exhibition, especially one with a strong historical and cultural background.

Going into more detail about VR experiences, the literature also provided insights that the level of visitor engagement is mainly dependent on immersion, interactivity through gamification, exploration and social interactions. Additional factors that are relevant to this project are concerns about usability and cognitive load, which could be particularly important to balance correctly for users that are new to VR.

While immersion appears to be an absolute necessity for engagement, gamification and interactivity are more nuanced areas according to the research. Both of these factors have great potential as well as risks related to the aforementioned usability concerns when employed in virtual museum exhibitions.

Lastly, social interactivity opens up a whole new field of research. While the currently available consensus is, that the concept of (co-)presence can be beneficial for engagement, the research is limited and does not suggest reliable methods of interaction to achieve high levels of engagement through SVR.

Overall, it is apparent that in the field of VR, plenty of research has been and is being conducted in for a variety of niche applications. Specifically, the employment of social VR in the context of an art exhibition for museums appears to be a topic that very few or limited scientific research projects have been conducted about. This is why it is necessary to continue the research, especially in the field of social VR, to reveal in finer detail how engagement in social VR experiences can be increased.

Despite this limitation, the reviewed research provided insight into many projects which can be compared to social VR in museums well because of their similarities in many underlying categories.

For this design project on a social VR exhibition in an art museum, it will be necessary to find additional research on comparable projects revealing the current state of the art for this niche application, which will therefore be discussed in the following section. Since current research seems to be generally limited, it will also be necessary to conduct thorough testing of the interventions later in the process. A special focus herein should lie on the development, evaluation and subsequent iteration of social modalities in the virtual environment that contribute to immersion and co-presence and therefore engagement of visitors.

2.2 State of the Art

A review of published projects shows that a joined experience of multiple users in a virtual museum exhibition is currently a rare use case of social virtual reality. This is not surprising, given the limited research on this specific niche of virtual reality as a whole. Despite this, there are two projects that are closely related to the topic of this research project and should therefore be mentioned here. While there was some insight to be gained from these projects, single-user experiences that revolved

around interactive museum experiences were investigated additionally. One of which will be discussed in this section.

2.2.1 Museum of Other Realities

The "Museum of Other Realities" provides users with a highly interactive museum experience in a dream-like environment, which can be explored in groups of multiple people [18]. The museum allows visitors to dive into a dream-like world which displays many different digital exhibits in the form of three-dimensional structures and sculptures, as seen in Figure 1. It facilitates interactions through locomotion in various ways, such as teleportation, and floating but also by scaling the user down to experience a seemingly small installation from a different perspective within it. The experience is mainly aimed towards visitors that want to explore as much of the virtual environment as possible. Apart from full locomotion, users can also interact with spheres that contain 360° content, allowing for less need to walk around to find out more about different aspects of a topic of an exhibit.

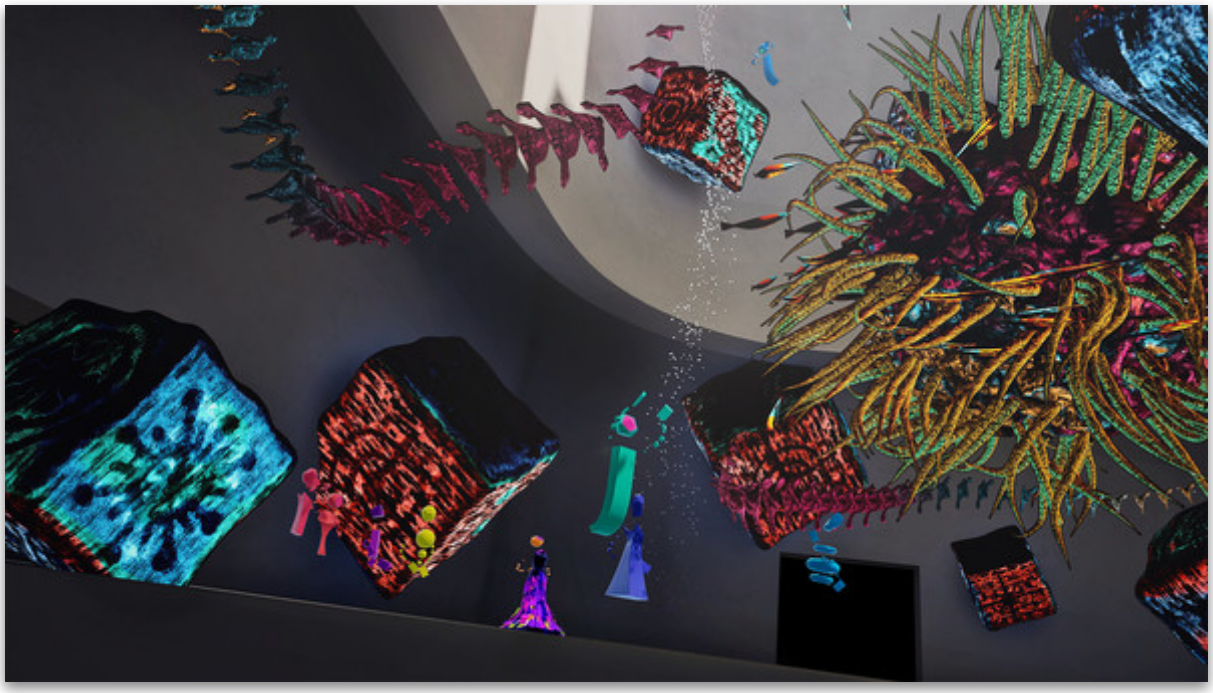

Figure 1: Museum of Other Realities - An Art Exhibit and Avatars

Rules of physics don't apply in the virtual space, which allows for a supernatural, dream-like experience in an environment that has its very own special aesthetic. There are floating particle systems, whole worlds in different scales within one another and portals to other virtual worlds with their own exhibits. Visitors of the museum of other realities are embodied in the virtual environment with a simplistic and abstract avatar, that appears in one solid colour and consists of simple shapes like cones and spheres. The project was released to the public as a commercial product in 2020 and has since received a very high user rating on the software distribution platform Steam [19].

While many users are happy with the experience, some pitfalls of the project are the complex options for interaction and the surreal visuals of the virtual world, which can both be confusing and disorienting.

2.2.2 Mediascape XR

The second project that should be highlighted within the context of social VR is the "Mediascape XR" project by Reimat et al. [20], which was presented for a public demo for three days during the VR Days 2021 in Amsterdam. The VR experience allows multiple visitors to walk freely through the media museum of Beeld & Geluid (Sound & Vision), which is the company that developed the application together with Centrum Wiskunde & Informatica (CWI) [21]. This process can be seen in Figure 2. During the experience, visitors can learn about modern Dutch cultural heritage. Specifically, they can look at and even wear a costume originally worn by a famous Dutch singer in the "TopPop" show in the 1970s. The immersive experience even allows visitors to take to the stage themselves and reenact the show.

Figure 2: Mediascape XR - Visualisation of the User Experience

The whole museum can be explored by multiple users at the same time, which is facilitated by the VRTogether platform, on which the application is built using Unity3D. Visitors of the museum receive a body-scanned avatar of themselves before entering the museum experience. This avatar is a fairly realistic representation of the actual look of the person and therefore contributes to a high level of co-presence in the virtual environment [20]. While this feature has the mentioned positive effects, it also requires some amount of time for each user to set up before diving into the experience. This also means, that a staff member capable of operating the cameras and avatar creation software always has to be present. This is counterintuitive given that this project was meant to allow people to visit the museum from their homes during the times of lockdown during which the VR experience has been developed.

2.2.3 Sky VR: Hold the World

When looking at museum experiences in VR that are not designed for multiple users, one prominent name appears. Famous narrator Sir David Attenborough stars as a knowledgeable guide in the “Hold the World” experience, produced by Sky VR for the Natural History Museum in London [22]. In this VR experience, users can explore multiple rooms of the museum, interact with the artefacts they find and even place them in front of Sir David Attenborough to hear him talk about them in great detail, as shown in Figure 3 [22]. The rooms are scaled to their true size and the models of many exhibits, primarily fossils, are of the highest quality in terms of detail and accuracy. While the accuracy of the models was achieved by 3D scanning their original counterparts, the virtual representation of Sir David Attenborough has been created with volumetric video. [23].

Figure 3: Sir David Attenborough in Sky VR: Hold the World

These technologies provide outstanding visual fidelity for a virtual reality experience that aims to look life-like, but they come at a high cost. While Sky VR and the Natural History Museum can provide a sufficient budget to create an experience of this quality and sell it for as little as 4€, it may not be a viable solution for other institutions [24]. In addition to the high cost during development, this system also provides little room for expansion. Due to the nature of the pre-captured volumetric video, each newly added exhibit would require a new recording done in a suitable studio. This is a significant downside and also means that little elements of the actual program would be transferrable to a new, totally different, exhibition in the future.

Apart from these pitfalls for future development, the experience shows what is possible with the current state of virtual reality hardware as well as software. In terms of educational as well as visual fidelity, “Hold the World”, which was released in 2018, is still the best product that aims to bring the museum in its familiar look to virtual reality. There does not seem to be any other product publicly available that can provide a similar depth of information in this type of realistic environment.

2.2.4 Discussion

The first two presented projects enable users to dive into a virtual world together with at least one other person that is also immersed in the same VR experience. This is the basic idea of social VR. However, each of these projects takes a different approach to show their museum environment, with positive as well as negative aspects to them regarding the user experience. While the “Museum of Other Realities” aims to create a very complex and colourful world, this may not always be positive for user engagement. The previously evaluated research showed that less complexity is often best, even though interactivity and possibilities for exploration generally boost engagement. In this case, the fine line between just right and too much may have been crossed for some users, especially those unfamiliar with the technology. The visual style combined with the complexity of interactions, therefore, does not seem to be suitable for the average visitor of an art museum, but rather for individual users that own a VR system and have at least some experience with VR and games to be able to quickly understand and master the controls.

On the other hand, the “Mediascape XR”-experience aims to create a natural environment that represents the real-world equivalent as well as possible. In the reviewed literature, co-presence has been found to be an important factor for immersion and therefore engagement, which is implemented to a high degree in “Mediascape XR”. Combined with the level of interactivity provided in the demo, the "Mediascape XR”-project seems to accomplish many of the goals that could be extracted from the literature. Going forward, it will serve as a positive example for these aspects, even though the incorporation of body-scanned avatars is not within the scope of this project.

Even though many positive points can be found for the SVR projects, comparing them to “Sky VR: Hold the World” shows that with current VR hardware, SVR experiences cannot offer the same fidelity as single-user experiences. While not having a truly social aspect, “Hold the World” does not only offer a virtual guide but one that most users likely know as the famous narrator already. This circumstance paired with the fact that it allows for a much more sophisticated educational experience shows where social VR needs to improve.

For this project, aspects implemented in “Hold the World” should be considered to achieve a greater educational value while making use of a truly social environment with multiple real users. The fact that the virtual environment of the exhibition “HERE: Black in Rembrandt's Time” is kept in the style of the actual rooms of the museum gives this conclusion even more significance.

Chapter 3: Methodology

In this chapter, the general design method used for this project will be explained. Additionally, the specific implementation of methods for this design project will be elaborated on.

3.1 Design Method

This research is carried out as a graduation project for the study program Creative Technology. Because of this, the design method that will be used is the “Creative Technology Design Process” which has been established by Mader and Eggink[25] in 2014 and has since been used effectively in design projects concerning the broad field of creative technology with the aim to produce functional, high-fidelity prototypes within a limited amount of time.

The focus of this design method lies in the possibility to turn any linear design process into an iterative process, which allows designers and researchers to return to a previous phase of the design process to improve it. This makes the design process highly adaptive to new insights and results from intermediate testing and evaluation. Additionally, this provides a high level of flexibility for projects that are tied to fixed time constraints. Being a graduation project with a fixed length of two quartiles, this project is no exception to that, which makes this method all the more applicable.

The process is split up into three main phases, each of which starts and ends with a set of intermediate results [25]. After first defining a design question the first phase of the main design process is ideation. From this very important phase, ideas for a product or an experience emerge. In the case of this project, this phase is used to produce ideas for interactions that could be used in the context of the VR art exhibition. To find these ideas or concepts, stakeholders have to be identified, user needs have to be defined and previous research on the topic as well as related work has to be considered. With this in mind, the actual generation of creative ideas and approaches to the task can be facilitated by using different creative thinking methods.

The second phase of the design process is the Specification phase. In this phase, the ideas for a product or experience are refined to ensure that the final outcome will be of high quality. By more narrowly defining the actual user experience and functionality of the product, the project also becomes more feasible in this phase. At the end of the Specification, the first prototypes can be produced for early evaluation. At this point, it is common to go back to the ideation phase to come up with a better or more feasible idea, in case the early prototype showed significant flaws or technical challenges that cannot be overcome.

After reaching the point at which an early prototype with a more specified general concept has proven to be a valid solution to the design problem, the final phase of the design process, the Realisation, begins. To go from an early prototype with likely limited functionality to a more finished product, all aspects of the plan have to be implemented individually. At the end of the Realisation phase, there is a finished prototype of the desired experience or product, which can be used to evaluate the initial design question.

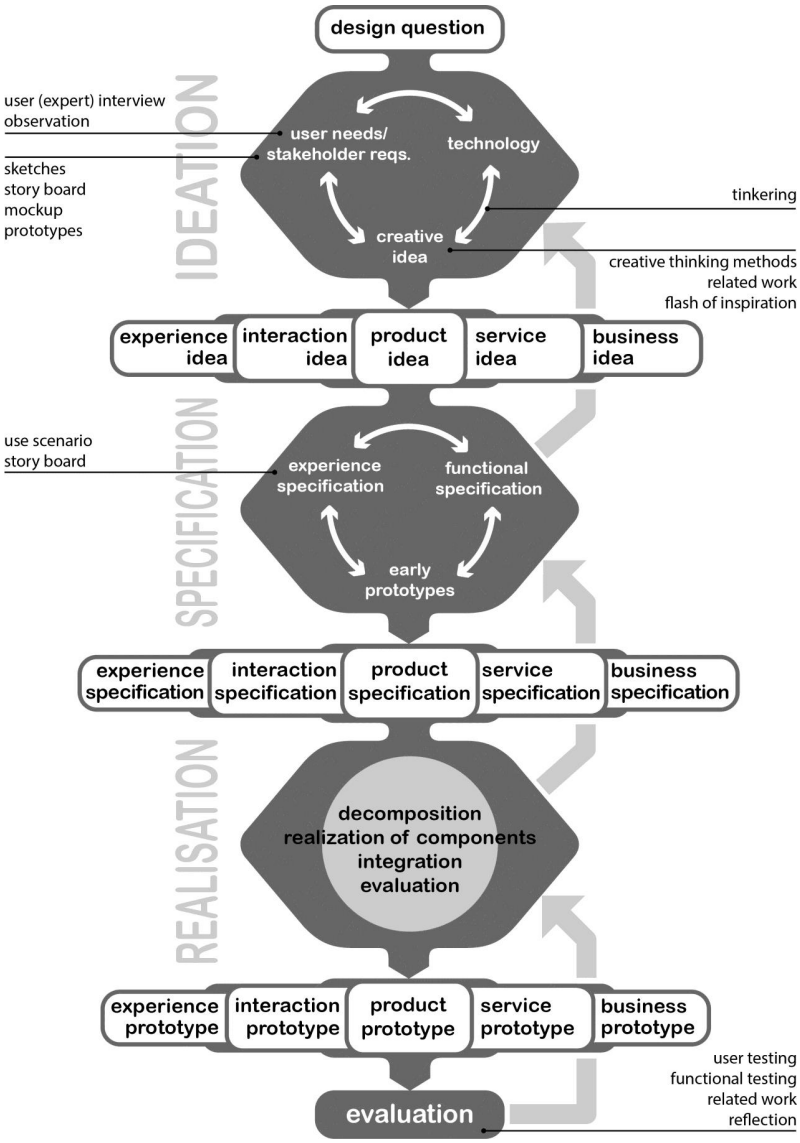

Figure 4: Flowchart of the Creative Technology Design Process

3.2 Implementation

The Creative Technology Design Process, depicted in Figure 4, provides a stable framework for many design projects that have the primary aim to produce functional prototypes. For this particular project, the following specific methods have been used during the three design phases.

Ideation:

For the ideation phase of this project, the ideas for possible interactions were generated using a combination of popular creative thinking methods. To come up with interactions that can a more socially connected VR experience, a modified brainwriting method was used. In this particular case, this method consists of 10 minutes of brainwriting followed by 15 minutes of iteration and finally 5 minutes in which the best ideas are selected. Brainwriting describes the activity of writing down every vague idea that is on one's mind within a defined amount of time. In this case 10 minutes. The goal of this is to generate a high number of ideas that do not necessarily need to be feasible or complex, but rather provide a starting point for the iterative phase. In this part of the idea generation, the less

strictly enforced time limit of 15 minutes was used to develop the initial ideas into an idea that may be feasible as well as appropriate to the base requirements of the project. Finally, a set of ideas were selected to continue with more in-depth iteration, generating options for prototypes that could satisfy all requirements eventually. Additionally, some general tips proposed by Schell [26] were incorporated into the process of generating and finding ideas, such as listing generated ideas in numbered lists to give them more individual significance.

Specification:

During the specification phase, all requirements, functional as well as non-functional, needed to be defined. To achieve this, user personas were defined that represent possible approaches to the use of the prototype. With the use of these personas, the list of requirements can quickly become more complete by allowing the researcher to look at the potential use of the prototype through different lenses. To achieve a higher efficiency during the realisation phase and ensure the completion of a functional prototype at the time of the first user test, the MoSCoW method for prioritisation was implemented [27], as it is a popular method that has been implemented in the majority of projects during the study programme. Despite some downsides, this method was therefore the optimal option to prioritise requirements with regard to the time constraints of this project

Realisation:

Implementing the different components defined in the preceding design chapters required using the SVR platform NeosVR. The tool used in NeosVR to give interactive functionality to all components was the node-based programming system LogiX [26]. The approach for the realisation was based on the hierarchical list of requirements from the previous chapter that defined which components needed to be implemented first.

Evaluation:

To evaluate the final ideas concerning the research question, user testing of a functional prototype is crucial. Therefore it was used to measure the performance of the final prototype with regard to the research questions. The same exhibition was tested in two settings to test the relative effect that the designed interactions have on the engagement of the participants. Furthermore, results were obtained using interviews as well as standardised questionnaires for reliable analysis.

Chapter 4: Ideation

This chapter defines the starting point of the design phase. It contains the process and outcome of the Ideation, which also entails stakeholder identification and the elicitation of user requirements. Analysing the stakeholders and their needs for an interactive experience was necessary to set a general guideline for the generation of possible concepts later on in the chapter. Furthermore, the generation, selection and iteration of concepts will be described. Lastly, the chosen concept in the form of a final iteration thereof will be elaborated.

4.1 Stakeholders

The goal of this project was to develop a more attractive way for young people to visit art and history exhibitions. These young people define the primary stakeholders for this project and were the most relevant stakeholders for the generation of possible concepts for interactions. While they all have different attitudes toward going to art and history museums, people under the age of 30 are generally less inclined to go to such exhibitions [1]. To counter this development and provide an experience that intrigues these people to actually make use of a social virtual reality exhibition, they had to be considered first for all design considerations. During the ideation of concepts, design principles that were identified to create engagement in the reviewed literature should be considered. Most importantly, a concept should provide ways of interacting with the game world as well as another person in the virtual world, as these are key components to the engagement as well as the approach of this project. Additionally, the complexity of the considered interactions should strike a balance between the educational value that is being offered and the usability for an audience with mixed proficiencies regarding the technology.

Next to the primary stakeholders, the visitors of the exhibition, secondary stakeholders need to be taken into consideration in the generation and ideation of concepts. In the case of the exhibition “HERE: Black in Rembrandt’s Time”, there are three secondary stakeholders that can be identified. The Rembrandthuis Museum in Amsterdam, where the physical exhibition was originally displayed, has an interest in this digital experience of their exhibition. For the museum, like any other, the educational value is of concern. Especially, when working with a type of media that may require shortening certain aspects or adding new ones to the existing exhibition, the educational message needs to be conveyed accurately. The same concern is true for the curator of the original exhibition, who takes a special role as a stakeholder that is affiliated with the museum, but also has a unique perspective on the exhibition. For them, it is important that the intentions they had with the arrangement of paintings, wording of informational texts and more generally the selection of exhibits are transferred to a virtual version of the exhibition they curated. Since this project works with a digital version of the exhibition that has been produced beforehand, the concerns for the generation of concepts should be more focused. Concepts should allow for a realisation in which there is no necessity for removing, changing or adding content to the exhibition that could change the message of the installation. Finally, this leads to the third group of secondary stakeholders. People that consider themselves part of the cultures and communities that the exhibition “HERE: Black in Rembrandt’s Time” is concerned with have an interest in an accurate representation of their heritage. This should

be kept in min early during ideation to avoid following concepts that may be sound in terms of user experience but lacking in terms of accuracy concerning the cultural heritage of people of colour living in the Netherlands in the 17th century.

These stakeholders and their needs were considered during the following generation of concepts to improve their feasibility and applicability for the later design phases.

4.2 Initial Concepts

With the defined baseline requirements in mind, several viable concepts with varying complexity were generated. As described in Chapter 3, this was done with a modified brainwriting approach. To come up with a large enough set of ideas, 10 minutes of writing down all ideas was followed up by 15 minutes of iterations over the individual concepts. After this step, the final concepts that were deemed viable were selected.

This initial idea generation phase yielded a broad selection of ideas, of which a detailed list can be found in Appendix A. These concepts provided the starting point for further iterations and recombinations of concepts. While each concept detailed a different interaction for users to have with the virtual environment, they could be divided into four groups:

1. Passive gain of information
2. Search interactions
3. Quiz interactions
4. Interactions with physical objects

Concepts that were categorised under “Passive gain of information” included complex ideas such as the addition of animated characters in the style of the figures in the paintings or a change of the environment to immerse the visitor fully in the Netherlands of the 17th century. These ideas were quickly discarded for two reasons. They were too complex to implement given the scope of the project and they did not provide a sufficient level of interactivity, which is needed to achieve a high level of engagement.

On the other hand, plenty of elements from the latter three categories seemed promising. Implementing an element of search that required users to explore more of the virtual exhibition was present in multiple concepts with the reasoning that exploration also plays a role in engagement. On top of that, giving users an explicit or implicit task to look at more details within the exhibition appeared to be a good way to improve the connection of users with the educational aspects of the exhibition. Another idea within this category was to start users on different ends of the exhibition so that they would only find each other after already seeing parts of the exhibition. While simple, the premise of this idea was to foster verbal interactions between users. This would make use of the social VR environment and nudge users to talk about what they had seen in the exhibition before meeting one another. Similarly, the main idea behind the concepts categorised as a quiz-type interaction was to have users discuss the meanings behind the paintings in the exhibition. Apart from that factor, quizzes of different forms have been used in education to great effect for a long time.

Finally, interactions with physical objects appeared among the concepts as well. As it was shown in the “Sky VR: Hold the World” experience [22], this type of interaction seemed like a logical step to implement in a virtual museum. The reason behind this is that virtual museums, unlike actual

museums, do not need to account for property damage and theft. Therefore, it is possible to move exhibits or parts thereof as a 3D model around the museum, allowing visitors to take a closer look at objects or perhaps compare two paintings next to one another that were originally placed in different rooms.

4.3 Selected Concepts

After discarding unviable options and selecting the most promising ideas, two main approaches emerged. The first concept for the prototype of an interactive exhibition was based on the idea that users should be able to grab and inspect artefacts from the exhibition. Largely inspired by the experience “Sky VR: Hold the World”, the concept for the exhibition “HERE: Black in Rembrandt’s time” entailed that users would be able to hold and inspect items from within the paintings. This interaction both promised to be engaging since it offers users a sense of connectedness to the exhibits that would also not be possible in a real museum. From an educational perspective, taking a closer look at specific items in a painting may give users a reason to think about the historical context of these items. On the social side of things, placing an array of interactive objects in a virtual exhibition would give users the chance to explore individually and share their findings with one another each time they meet in the virtual space.

The other avenue that was explored in the second round of iterations was the concept of an interactive quiz. The quiz could be implemented as a social activity in which users have to work together and share their knowledge gained during their exploration of the exhibition. This would make good use of the social virtual reality environment, which features a voice chat system. The contents of the quiz were envisioned to be a variety of topics ranging from the artist's style to the historical significance of the representation of people of colour in art. Visually, the concept for the quiz was initially thought to be a 2-dimensional area around each painting. The actual quiz would then have consisted of a matching interaction of different icons to slots around the paintings. This idea was discarded in favour of a more traditional layout of a text-based quiz in a central location of the exhibition. This quiz would consist of questions on the paintings with a focus on the stories behind the persons in the paintings of the exhibition “HERE: Black in Rembrandt's Time”. Since this is also the main area of focus of the exhibition in general, this approach promised to be of high educational value.

After looking at both concepts, it became clear that both of them had significant downsides. While the ability to interact and inspect objects may be engaging, it is lacking a sufficiently sophisticated educational component that would help users understand the content of the exhibition. On the other hand, a quiz may be suitable to educate visitors of a museum but takes little advantage of the virtual environment. It therefore lacks options that would increase immersion and engagement which is especially needed for younger users, which the final product of this project was supposed to be aimed at.

Since the downfalls of one concept were the strengths of the other, the final iteration of a concept for an interactive exhibition was set to be a combination of the two. This entailed that the inspection of objects would become a central and necessary component of the quiz. The other way around, the interactive quiz should prompt users to search and retrieve objects to continue with the

next quiz question. This combination of concepts finally combined the main strengths of each avenue that was opened during the initial generation of ideas.

4.4 Final Concept Iteration

After the decision to combine the two interactive concepts was made, the concept for an interactive quiz with a “search and retrieve”-quest component was revisited. The final iteration defines the user journey, which is also described in Figure 5 on the following page, through the experience as follows:

At the starting point of the exhibition, visitors find themselves in a room with an empty pedestal in the centre of it. On the wall behind the pedestal, a large area is covered and used to display a simple instructive text. In two sections, the text tasks the visitor of the museum with finding a specific object in one of the paintings within the exhibition and returning it to the pedestal. The text contains the incentive to return the item to learn more about the story of the object and the person in the respective painting.

When they leave the room, users can explore the rooms of the exhibition “HERE: Black in Rembrandt's Time” in the layout chosen by the original curator. After taking a look at multiple paintings, the visitors may find the object they were looking for. By pressing the grab button on the controller while pointing at the painted object, a 3D version of the object in front of its 2D original on the painting appears. Visitors can inspect the object from all sides. Then, they can return the object to the pedestal on which it has to be placed. Once that has been done, the text area on the wall will change from the search prompt to a quiz question on the object itself. Each question has 3 options for an answer, of which one is correct, displayed in boxes that can be selected by pointing at them and clicking the selector button. The correct answer will be revealed and the users will receive visual and auditory feedback. Apart from being able to see the correct answer, the text will provide users with additional information on the object and its connection to the person in the respective painting. This information can put the object into a historical perspective that could otherwise not have sufficiently been touched upon by just the normal text next to the paintings alone.

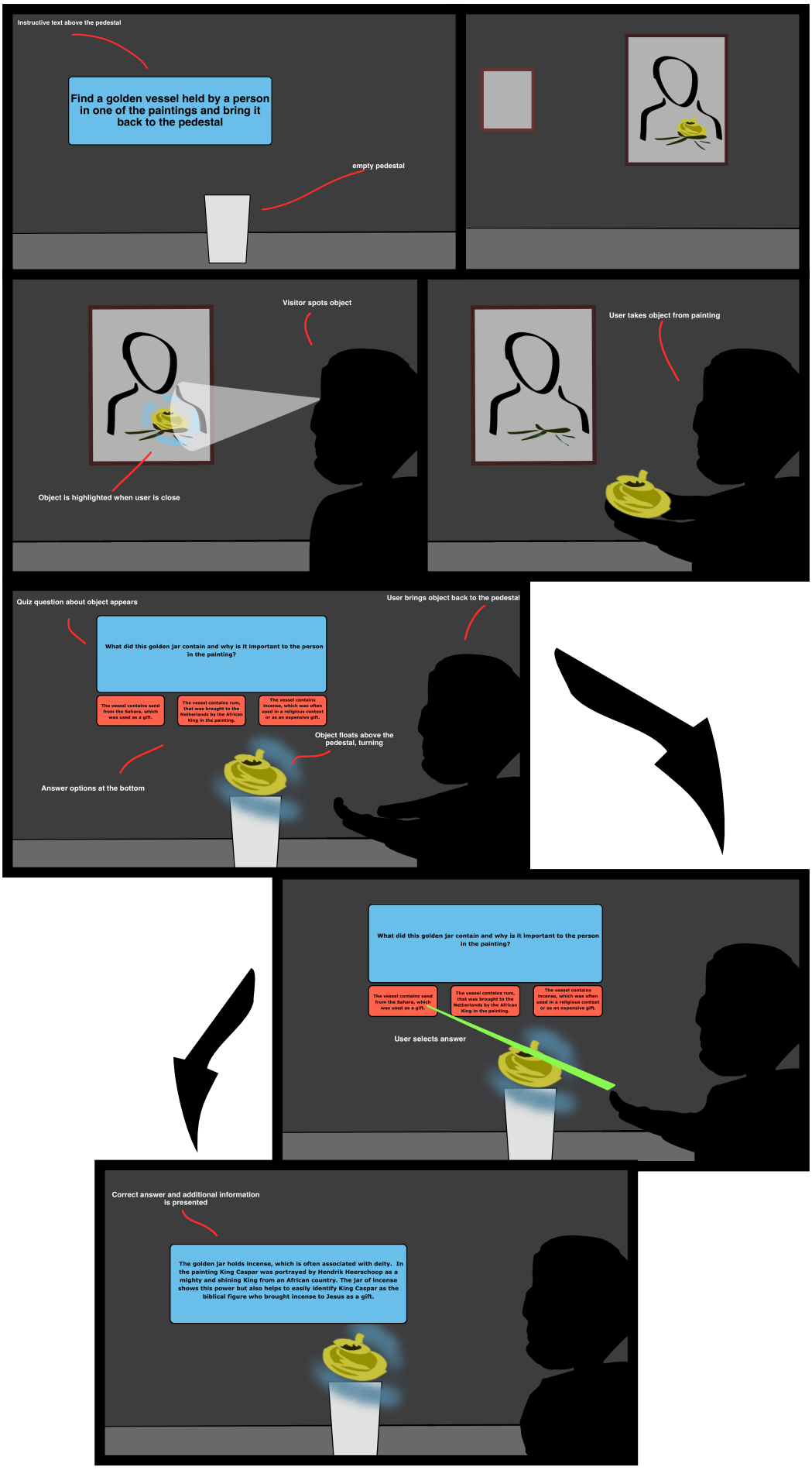

Figure 5: Storyboard of the Final Concept

To define the details of the final concept that were specified above, all options that were seemingly suitable were arranged on a mind map, as shown in Figure 6. In this case, the areas were separated into three main branches. World interactions, social aspects and rewards. The latter was important to take into further consideration to ensure that the gamification aspect contributed to the engagement of the user. Defining, which social interactions could potentially come into play, was useful to see early on if the potential of the social VR environment was used. In this case, it should be used to foster engagement, but also potentially improve the understanding of the cultural heritage presented in the exhibition “HERE: Black in Rembrandt's Time”.

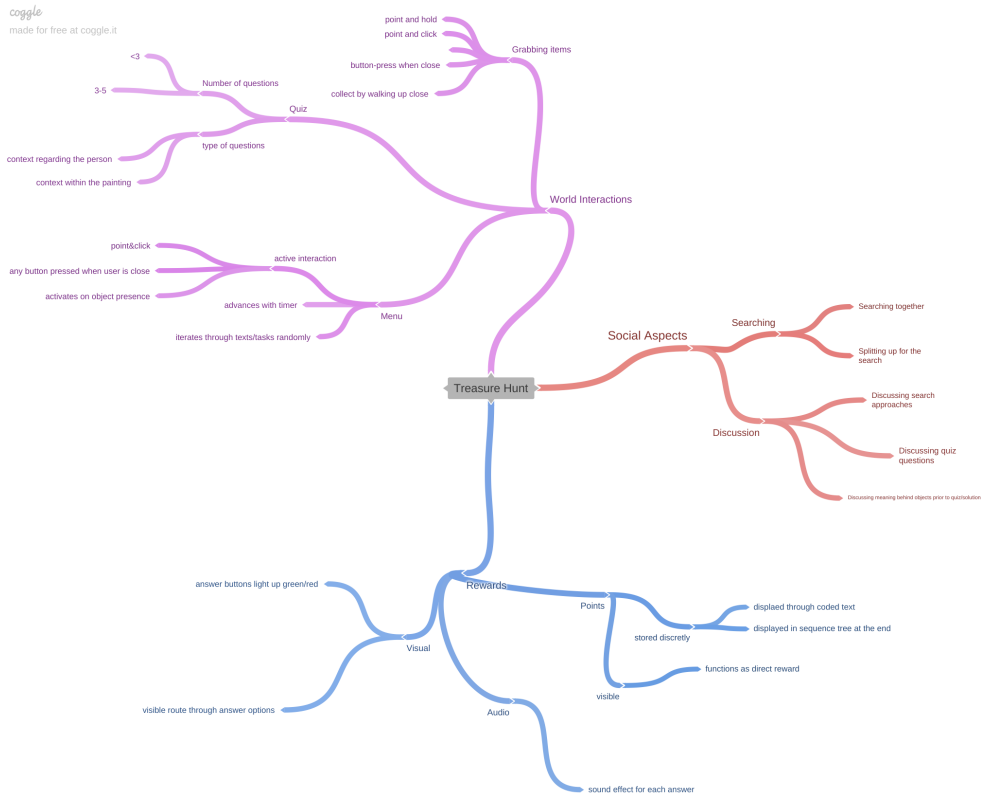

Figure 6: Mind Map for the Final Concept

Furthermore, the potential interactions with the different elements in the virtual world needed to be investigated. For this branch, multiple options for each interactive component were considered that would become relevant in the following chapter on specification.

This final iteration of the concept was chosen to be used going forward in the design process for multiple reasons. To summarise, it showed a feasible approach to creating an interactive exhibition that goes in accordance with the findings of the literature review. In terms of the approach to designing an engaging experience, considerations regarding immersion and interactivity were made. Furthermore, some of the successful or promising approaches from currently available virtual reality experiences, for example, the interaction with exhibits as physical objects, were incorporated.

Chapter 5: Specification

This chapter is dedicated to the more specific aspects of the concept. It includes the requirements for making it as well as a selection of stakeholder personas that help with making sure that all stakeholder needs are met and the final prototype achieves high usability for its intended target group.

5.1 Stakeholder Personas

To better understand the possible needs of stakeholders, I created a set of fictional personas that can represent the target group of young adults that are looking for a more engaging and interesting experience in a museum.

1. Sven, male, 24

Sven is a university student in a master's study in mechanical engineering. While he is certainly interested in gaining knowledge and achieving a high level of education for himself, most exhibitions presented in traditional art and history museums never spoke to him enough to actually take the time to read about the information. In his free time, Sven occasionally plays video games. He has tried VR games a few times but does not own a device himself. If he goes to a museum, it is usually a modern and interactive science museum where he would go together with his friends and try out all interactive functions but not read the information in text form.

2. Mia, female, 19

Mia just finished high school and is looking to start an apprenticeship in fashion design. She enjoys the fine arts and sometimes goes to art museums herself. History however is of no interest to her and she never reads the explanatory texts next to the paintings. To her, the symbolic meaning, visual composition and textures are more interesting. She has never used a VR headset before and does not usually play video games.

3. George, male, 27

George is a carpenter and has been for almost 10 years. He finished school at the age of 16 and started his apprenticeship shortly after. During this time he rarely ever visited any museums, as they were no longer interesting to him. He enjoys spending his free time with his friends and frequently plays casual online games after work. He has tried using a VR headset once at a friend's house but got motion sick due to the rapid movements of the game he was playing.

4. Alice, female, 21

Alice studies law and thinks highly of her own intelligence. She used to go to museums with her family and kept the habit after moving to a university city. Now, she goes together with her friends. While she usually reads all the information that she can find for individual exhibits, her friends often get annoyed because they would like to move on, which lessens her enjoyment of the experience. In her student house, she has a game console and a new VR headset that she uses to play single-player VR games. She has tried social VR chatrooms, but found them to be too chaotic to enjoy.

Based on these Personas, a multitude of use cases and styles can be identified. For users that are not familiar with the technology, it would be important to provide thorough instructions on the controls and limit their complexity to not overwhelm these users. On the other hand, users that are familiar with the technology might be looking forward to an interesting experience that makes good use of the VR aspect. Therefore, striking a balance between complexity and simplicity is crucial. This may also influence the likelihood of motion sickness to occur among visitors of the virtual exhibition.

Besides concerns about controls, different types of users may approach the educational contents of an art exhibition entirely differently. For this aspect, again, a balance needs to be found between the amount of information and general user interest. A solution may be to deliver educational content as a reward in small amounts at a time, to not overwhelm the user, but to intrigue them into the topic in a gradual fashion instead. The language and contents should additionally be simple enough for all types of visitors to understand, whether they have background knowledge concerning art and history, or not.

Finally, an interactive exhibition provided through a novel medium such as VR, which is primarily associated with gaming at the time, should allow users to have fun with the possibilities presented to them. Therefore, despite having to strike a balance for multiple aspects influencing the use of the interactive exhibition, it should provide the users with a sense of enjoyment rather than frustration about the technology.

5.2 Requirements

There are functional as well as non-functional requirements that have been established for the prototype of the interactive exhibition. The requirements were primarily inferred based on the final concept and the storyboard provided in the previous chapter. Additionally, the analysis of personas and general stakeholder requirements were used as an aid to generate a complete list of requirements. The main goal of establishing these after choosing a concept is to create a high-quality prototype within a limited scope in terms of time and human resources.

To create a prioritised overview for the realisation phase, the MoSCoW prioritisation method was applied [27]. This list comes in handy when trying to see what needs to be done during the realisation process at a glance. Since it does not have a high expressiveness without context, it will not be included in this section but can be found in Appendix B. Instead, however, all significant requirements will be covered in the following paragraph to provide valid reasoning for their inclusion as a requirement for the final prototype.

5.2.1 Functional Requirements

To implement the concept defined in the ideation chapter, multiple requirements needed to be established before starting the development. The following items are necessary for the interactions of the final concept to work as intended.

First and foremost, 3D models of the objects in the paintings need to be created. At the minimum, three objects must be created to enable users to have a meaningful progression in their experience during a user test. Adding more objects is necessary for a final product, given sufficient educational material in the paintings of the exhibition “HERE: Black in Rembrandt’s Time”.

The created objects must also be interactive. Users must be able to instantiate an object while they are looking at the painted counterpart of the object. Additionally, users must be able to grab and carry the objects to the pedestal defined in the conceptual storyboard. This pedestal must include two functionalities. For one, it must be able to detect objects that have been let go of by the user in its vicinity and have them hover above the centre of the pedestal. Secondly, the objects must be identified to trigger the correct progression of the quiz interface.

The quiz interface must feature two-dimensional text areas that display the prompts, questions and answers of the quiz interaction. Additionally, it must feature buttons that function as the answer options as well as a single button that can be used to continue with the next text field. This continue button can be presented to the user with each text field that displays the answers and additional information to the previous question. All buttons need to progress the quiz in the correct manner. This entails, that selecting an incorrect answer option should result in a different text that is displayed as an answer with additional information. While the information should remain the same, the text should specify whether the given answer was correct or incorrect to give feedback to the users.

Each object should have at least one question concerning its meaning in the context of the painting it is from. For each question, there should be at least three possible answers to choose from, of which exactly one should be the correct answer.

Users must be able to move around the virtual exhibition freely. This entails locomotion through the virtual world as well as a way to manipulate the first-person camera view.

Lastly, the prototype must allow for multiple users to be in the virtual exhibition at the same time. This requirement can be seen as a baseline for the social component, however, it is of little concern during the realisation since it is implemented in Neos VR, the platform used as an engine for the project.

5.2.2 Non-Functional Requirements

Apart from the necessary elements that require implementation for the prototype to function, several other design decisions have to be made. The following items are requirements for the prototype that need to be fulfilled to achieve the desired effect of providing users with an engaging and interactive experience.

First and foremost, the content of the quiz interaction must be well-defined, to provide an educational, yet entertaining experience. Based on the background research as well as the established personas, the balance between gamified entertainment and educational value is crucial to the success of an educational interactive experience. Therefore, the level of challenge for the prompts and questions should be adjusted to the expected level of expertise of the intended user base. Additionally, the contents of the final answer should contain an interesting story that helps visitors understand the topic of the exhibition and the specific person connected to the object better.

Furthermore, the 3D models of the individual objects must be of high fidelity in terms of visual accuracy when compared to their painted counterparts. This is required to achieve a higher level of immersion since models that are too simplistic might break the illusion of holding the actual object from within the painting. Detailed objects are also required to represent the intentions of the original exhibition with regard to the presented cultural heritage correctly. Likewise, the content of the quiz must also treat the heritage respectfully.

Another non-functional requirement is the inclusion of adequate feedback in the form of sound effects. Users should be notified with a sound in the case of incorrectly matching an object to a prompt. This should help with the perceived ease of use while minimising frustration caused by failure to correctly complete the interaction. Similarly, a sound effect should play as a result of selecting a possible answer. According to whether or not the selection was the correct answer to the question, a typical success or failure sound should play.

Based on the reviewed research and commercial projects in social virtual reality, the concepts of presence and co-presence should not be overlooked when developing an SVR experience [14]. Therefore, the users should have an avatar as a virtual representation of themselves in the virtual world. Additionally, enabling users to have non-verbal communication by using an avatar as well as allowing them to see each other well in the game world, may help with orientation and immersion as well.

While developing a VR experience of any type, motion sickness must be addressed to some extent. This is particularly true in the instance of this project which is meant to be used by users with varying familiarity with VR. Especially first-time users encounter motion sickness more frequently [29]. An effort to mitigate this should be made with the tools at hand in Neos VR.

Chapter 6: Realisation

This chapter details how each individual aspect was ultimately implemented to make a working prototype that is ready for user testing and subsequent evaluation. The explanations regarding the implementation of different components are separated based on their category in terms of platform, programs used and connection within the final prototype.

6.1 Modelling the Interactive Objects

For the final prototype, three objects were identified to be used for the search interaction. While more could be used in a production version of the virtual exhibition, the three selected objects allow the users to have a meaningful learning experience while also reducing the time needed to complete all tasks during a user test. Additionally, reducing the time spend in VR also helps to reduce the chance of adverse effects like motion sickness for participants of user tests. A full list of the paintings with objects that could possibly be used for the search aspect of the interaction can be found in Appendix C, Table 1.

The selected objects are the following:

1. An elephant tusk carried by Pedro, a supposed servant of Dom Miguel de Castro.
2. The beaver hat with a large red feather, worn by de Castro himself.
3. The golden jar of incense, held by King Caspar in the portrait by H.Heerschop.

Additionally, as an alternative or for added length of the interaction, the small box in gold, held by Diego Bemba can be used. The meaning behind these objects plays a significant role both in the composition of their respective artworks as well as the stories behind the people protracted in them.

To model these objects based on their references, the 3D modelling program Blender was used. Blender is a versatile 3D creation software that is free to use as well as open-source [30].

To create a model of the elephant's tusk, a cylinder object was modified with a bezier curve to recreate the curvature of the painted tusk. Additionally, the tip and bottom were modified to taper in a way that gives this simple object a slightly higher complexity.

Modelling the incense jar was done by using a sphere as a starting point and making use of the proportional editing mode in the program, which allows for a gradual modification of edges. This was used to create the bends and creases that give this object its shape and details.

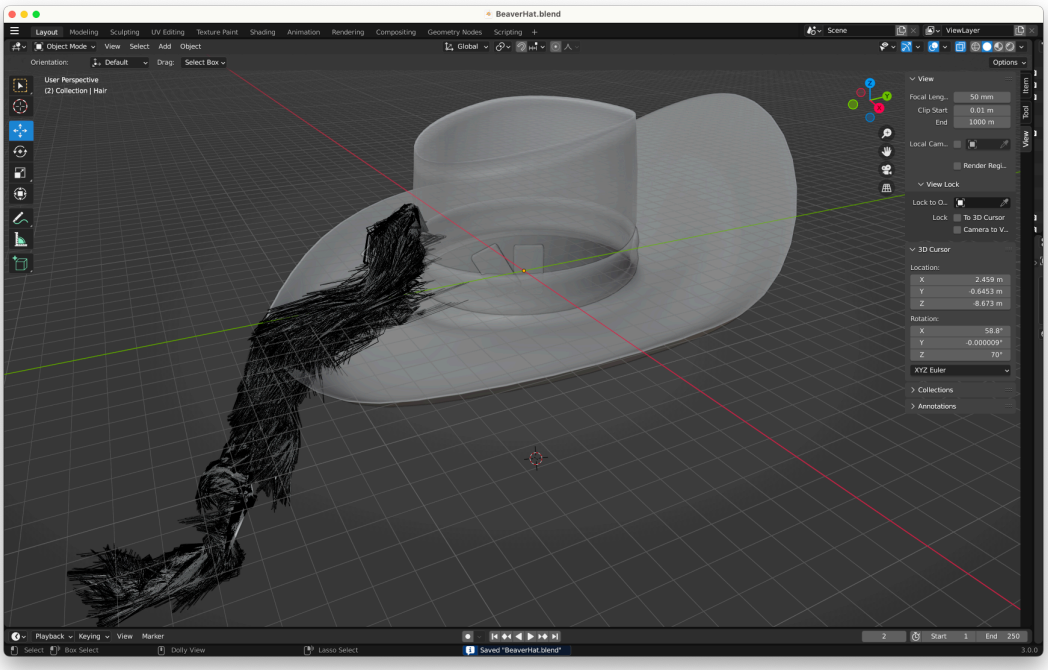

Figure 7: Model of Dom Miguel de Castro's hat in Blender

Finally, the most complicated object that was modelled was the beaver hat with the ostrich feather which can be seen in the Blender modelling environment in Figure 7. The hat itself was modelled from a torus using different techniques to correctly represent the bends and general shape of the painted hat. Additionally, the band with gemstones was added. The gemstones were represented through a height and normal texture map as well as a metallic and albedo map from a texture pack found on the online distribution platform textures.com [31]. The small gold bars that are decorated along the gemstone band were modelled by simply resizing a cube and then bevelling the edges.

Lastly, the feather of the hat had to be modelled. For this piece, a particle system placed on a path was created. To give a realistic impression of the feather of an ostrich, the individual hair particles were combed and dispersed. Once the hair particles were arranged in a sufficiently convincing way the object was converted into a mesh. This process also involved bevelling the individual strands of hair, which resulted in an elevated number of total polygons for this model. It also resulted in a loss of optical quality, as the hairs were no longer represented in their original, fine and detailed shape. This process was however necessary to ensure that the model would be imported into NeosVR without missing geometry or other complications.

Importing objects into NeosVR also leads to the loss of most materials that were previously assembled from albedo textures in combination with normal or height maps in Blender. Therefore, these materials had to be reconstructed in NeosVR after importing, using the material creation implemented on the platform. In that case, some materials from public folders in NeosVR were used in addition to the previously mentioned materials that were found online. More figures illustrating the objects that have been modelled can be found in Appendix C.

6.2 Contents of the Quiz

This section details all the texts that have been implemented in the quiz interaction. While writing these texts it was necessary to keep the original intentions of the exhibition intact and not ridicule the heritage that is being discussed. However, the options for answers required a gradual difficulty to them, to enable visitors to think about the question at hand and logically deduct the correct answer. Therefore, one answer option was meant to be relatively easy to identify as incorrect, whereas the two remaining options are roughly equally difficult, with one being the correct answer and the other being incorrect. This structure can help users feel rewarded by successfully going through the process of finding the correct answer without having a level of difficulty to the questions that would prohibit this. The quiz interface from the user's perspective after placing an object on the pedestal can be seen in Figure 8. It depicts the arrangement of answer options below the main text area used for the question. The hat object floating above the pedestal can also be seen at the bottom of the image.

Figure 8: Quiz Section about Dom Miguel de Castro's Hat

The information contained in the explanatory texts shown after an answer was given was curated from the original texts in the museum as well as from online sources that set out to analyse the paintings in great detail.

Since the quiz interaction was designed in a linear fashion, the three parts required to be structured in a logical way that had a positive impact on the story told by the installation as a whole. The two more prominent figures in this selection are King Caspar and Dom Miguel de Castro, while Pedro Sunda leaves a rather secondary impression in the original paintings. Even though this does not necessarily mean he has a lower historical significance, I decided to go with the following structure to attempt to reach the ideal middle ground between visitor interest and educative quality:

1. Beaver hat worn by Dom Miguel de Castro
2. Elephant tusk carried by Pedro Sunda

3. Incense ja held by King Caspar

This division allows the visitors to learn about Dom Miguel de Castro and his helpers in a linear fashion that allows for detailed insights into their story. Additionally, the painting of King Caspar, which is prominently featured at the start of the exhibition is highlighted with the last question. After reading an initial text, welcoming users to the experience, they were shown a prompt to initialise their search for the first item. The prompt reads:

"Your first task is to find a pompous piece of headwear!
Grab it from the painting and bring it to the pedestal!
You can grab objects using the grab button on the inner side of your controller.
Hint: The objects are hidden behind their 2D version on the paintings."

Similar prompts were written for the remaining quests, however, this one included the hint that objects are hidden until they are grabbed in addition to explaining the task itself. The prompts were written with the intention to give the reader a good understanding of the type of object they are looking for, while not giving away the exact painting or the name of the object.

While the grab function was explained in the instructions given to the users verbally during later testing, an additional hint was meant to reduce frustration, especially among first-time VR users. After returning the correct object, the first question regarding the hat of Dom Miguel de Castro was posed as follows:

"You found Dom Miguel de Castro's hat!
What materials do you believe this hat and the attached feather to be made of?"

Beneath the prompt, three options for answers were written as follows:

False option 1:
"The hat is made of rare antelope leather and the feather is one of a turkey."
False option 2:
"The feather is artificial and the hat consists of durable fabrics such as silk and felt."
Correct answer:
"It is an ostrich feather attached to an expensive hat made of beaver pelt."

After choosing an answer, visitors were given the solution to the question, containing the correct answer in an extended form as well as additional information about the item. On top of that, the objects' relevancy for the representation of people of colour during the 17th century was touched upon by the following text:

"The hat worn by Dom Miguel de Castro is made from Beaver pelt. Beaver hats were extremely valuable in the 17th century since the beaver had nearly gone extinct in Europe. It was only worn by wealthy people. While hats were often decorated with feathers, the large red ostrich feather attached to de Castro's hat is a rather exceptional example used to draw attention to Dom Miguel. Additionally, he decorated his hat with two small gold bars, a clear show of power and wealth.

Dom Miguel de Castro was in the Netherlands on a diplomatic visit after first visiting the colony of Dutch Brazil. His mission was to negotiate support from the Dutch West India Company in a conflict in the Congo. "

While his whole story within the context of the painting would be too long to tell, the visitors get more information about two aspects of the painting. For one, the hat and its significance are described [32]. As it is the most complex piece, the text goes over the different details of the hat. This would allow the visitors to take another look at the hat in front of them. After that, the paragraph about de Castro's mission gives further insight into his role and the reason for the painting to be made.

For the questions concerning the elephant's tusk held by Pedro Sunda in exhibit A7, the following question with corresponding answer options were compiled:

Question:
"You found the tusk of an elephant that was held by Pedro Sunda. What do you believe is the significance of this object in the context of the painting?"

False option 1:
"The tusk of an elephant is a symbol of aggression and strength and is used in this painting to show the power of Pedro Sunda."

False option 2:
"The tusk is made of ivory and was likely given to Pedro Sunda by the Dutch on his arrival to the Netherlands."

Correct answer option:
"The elephant tusk is made of ivory, a very expensive material and was brought to the Netherlands as a diplomatic gift."

The text that gives the full answer, as well as additional information concerning the context of the painting, was written as follows:

"The elephant tusk is made of ivory, an extremely expensive and rare material in the 17th century. Ivory was a major export product of the Congo at the time and was commonly as a gift on diplomatic missions. The man in the painting is Pedro Sunda, who was a part of the ambassadorial party visiting the Netherlands from the Congo.
Did you notice that he is wearing a green velvet suit with gold buttons? This was a fashionable style of clothing in 17th-century Europe, but also demonstrates the seemingly subordinate role of Sunda as well as Bemba compared to de Castro.
It is commonly believed that Pedro Sunda as well as Diego Bemba were servants of Dom Miguel de Castro, however, other paintings suggest that they were highly educated aristocrats in the Congo."

The information about the role of Pedro Sunda, as well as Diego Bemba, was found in an analysis concerning the three paintings of Dom Miguel, Pedro Sunda as well as Diego Bemba [33,34]. It showed an interesting perspective on the roles of the two seemingly subordinate figures that were touched but not expanded upon in the material of the original exhibition.

For the final object presented within the scope of the prototype used for user testing, the incense jar, held by King Caspar in exhibit A2, had to be retrieved by the users. The question they were asked when placing the vessel on the pedestal, is the following:

"You found the golden jar.
What did this golden jar contain and why is it important to the person in the painting?"

The three options that can be selected as answers are:

Incorrect option 1:
"The vessel contains sand from the Sahara, which was used as a gift."
Incorrect option 2:
"The vessel contains rum, that was brought to the Netherlands by the African King in the painting."
Correct option:
"The vessel contains incense, which was often used in a religious context or as an expensive gift."

After selecting their answer, visitors were presented with the correct answer to the question in a more extensive paragraph that is also touching on the actual person that was sitting as a model for this painting. The paragraph reads:

"The golden jar holds incense, which is often associated with deity. In the painting, King Caspar was portrayed by Hendrik Heerschoop as a mighty and shining King from an African country. The jar of incense shows this power but also helps to easily identify King Caspar as the biblical figure who brought incense to Jesus as a gift. The actual identity of the sitter portraying King Caspar for this painting is sadly unknown, however, the facial expression suggests that Hendrik Heerschoop did not just invent the person in this painting."

This information was deducted from the curated texts on the painting published by the Rembrandthuis Museum. Additional information on incense was found in an analysis of the painting [35]. After finishing all questions, the users were thanked for their interest and participation and invited to further explore the exhibition. In addition to the correct answers with more information, visitors were also given a short sentence indicating whether or not their selected answer was correct. This was placed at the beginning of each "answer"-paragraph.

The prompts given to the users to initialise their search were written in such a way that the exact object and painting are not given away, but that it is not a complete matter of guessing the correct object either. As an example.

6.3 Implementation of the Interactive Components

After creating the contents that were to be used for the interactions in the prototype, the system had to come together as a complete and functioning unit. That meant that both the contents of the quiz, as well as the objects modelled beforehand, had to be interactive to the extent they were specified and usable by any user. Additionally, all cases of human error had to be accounted for and addressed as needed. The main task that had to be accomplished for this final step of the implementation was to have a fully functioning interactive interface for the quiz, which also needed to react to the presence of certain objects on the pedestal in front of it. The secondary tasks for the

implementation were to define the areas in which the interactive objects would be instantiated if the user performed a grab interaction, as well as the possibility for those objects to snap to the pedestal once the user lets go of them while nearby. The whole process was facilitated with the use of LogiX in NeosVR. LogiX is a visual programming system implemented in NeosVR [26], which allows developers to use physical nodes in the Neos environment to program behaviour to any object in the virtual space. Nodes can be connected and represent objects, operators, values and more, as well as their possible actions.

6.3.1 Interactive Quiz Interface

To implement the interactive interface for the quiz, the subsystem UIX in NeosVR was used. UIX allows developers to create a canvas and fill it with components. The central components that were needed for the implementation of this interface were images, buttons and text fields. The image component was needed to display a solid background colour on a canvas. Due to the design of the interface, the different areas where text was displayed were created as individual canvases grouped underneath a main canvas with no background colour. This allowed for accurate alignment using the UIX boundary settings for each canvas. In total, 4 canvas components were grouped underneath the main canvas area. This allowed for one main field for text, used for prompts, questions and additional information, as well as up to three buttons that displayed the options for answers to the quiz questions. While the central button was always active to either display a possible answer to one of the questions or a continue button, the other two buttons were set to inactive unless they were displaying a potential answer to a question themselves.

To achieve the transition between different text contents on the canvas, an additional component, named *BooleanSwitcher*, was used. The *BooleanSwitcher* component can be used to enable elements from a list by driving the *Active* field of those elements [36]. It can take an integer value as an input and use it as a so-called *ActiveIndex* to enable an element from the list. The *Active*-toggle of the element on the list with the same index as the current *activeIndex* is then set to true. This causes the text element with the same index as the current *activeIndex* to turn to ‘active’, meaning that it becomes visible on the canvas. It also entails, that all other elements on the list that do not match the current *ActiveIndex* are inactive. Thus, by using the *BooleanSwitcher* component, multiple texts grouped under the same canvas component could not be active at the same time and therefore not overlap. This circumvented potential problems with the correct order and rendering of the text fields.

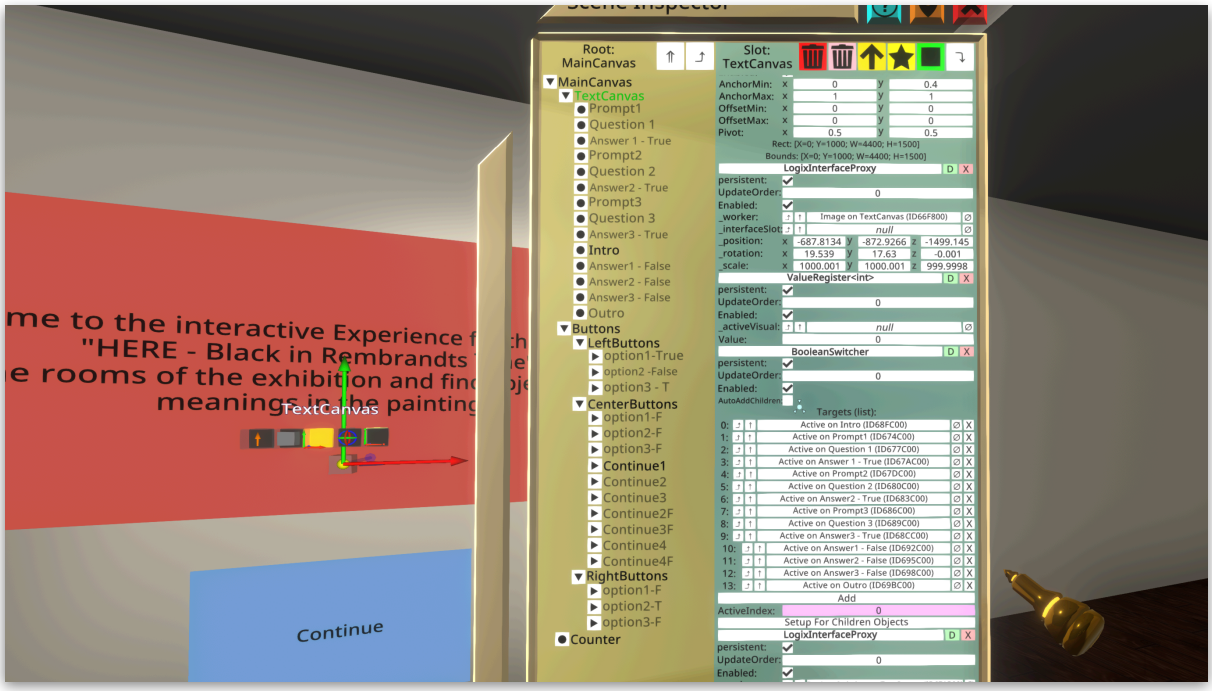

Figure 9: BooleanSwitcher Component on the Main Text Canvas

The intention of using the *BooleanSwitcher* component was to let the buttons on the canvas change the *ActiveIndex* of the *BooleanSwitcher* to the desired index. For example, the first continue button, as seen on the left-hand side of Figure 9, should advance the interactive canvas from the initial message, labelled *Intro* to the first Prompt, *Prompt1*. Therefore, the *ActiveIndex* would have to change from 0 to 1 if this specific continue button, *Continue1*, is pressed. This action could have been achieved by using the LogiX node *ButtonEvents* connected to the LogiX node of the button *Continue1*. This combination could have then been connected to the *ActiveIndex* slot of the *TextCanvas*. The standard LogiX operator, "++", for adding the integer value 1 to an existing value field would then have advanced this particular *ActiveIndex* from 0 to 1. This, however, would have resulted in an unnecessarily tedious and convoluted solution in the LogiX visual node environment, since the new index required to be passed to multiple *BooleanSwitcher* components. For each sub-canvas, namely the *TextCanvas*, the *LeftButtons*-canvas, the *CenterButtons*-canvas as well as the *RightButtons*-canvas, there was a list of *active* fields corresponding to each text entry in its respective area. To avoid having to create four visual connections in LogiX for each button event, a centralised *Counter* value field was used instead. This reduced the necessary connections for each button event to one. The *Counter* value field was used to store a centralised index that was connected to the 4 *ActiveIndex*-fields of the separate canvases. This meant that the value field on the *Counter* object drove those 4 fields, making them appear with a pink background colour, as seen in Figure 10.

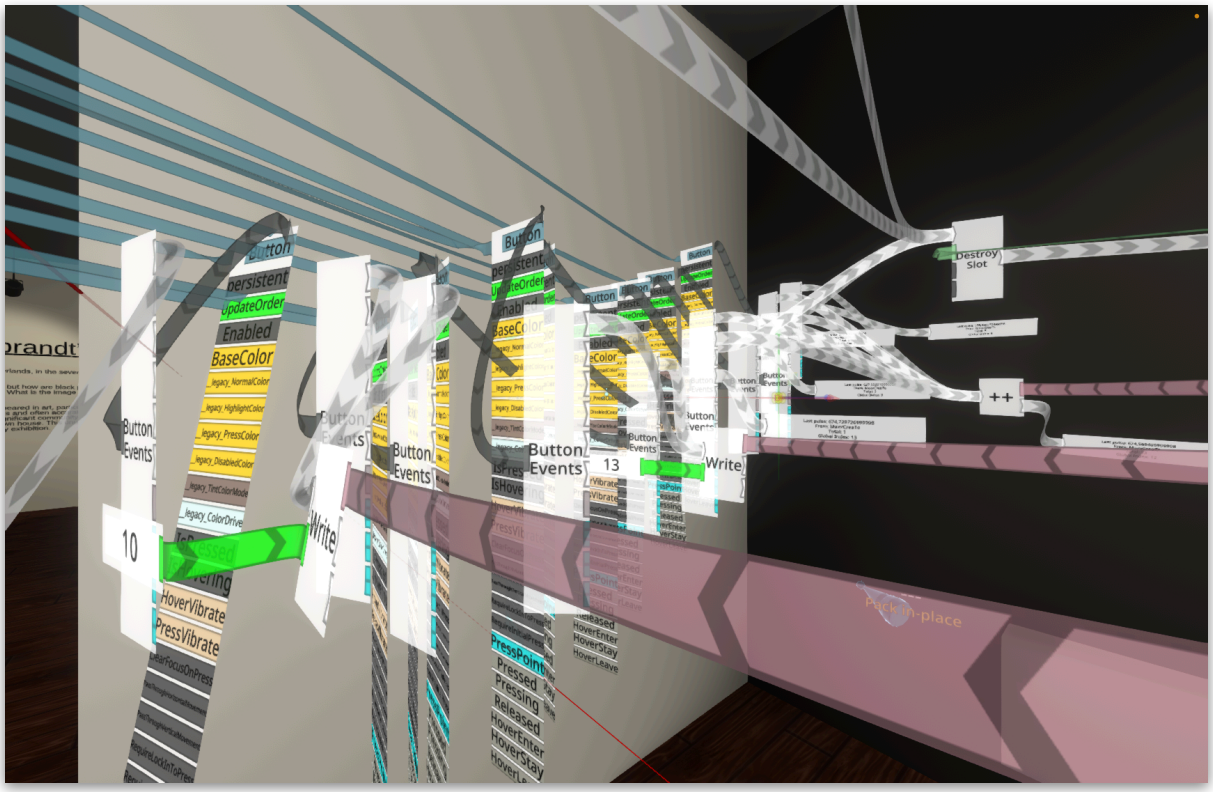

Figure 10: Button Event Nodes for the Text Canvas in LogiX

Using a centralised index variable also required the lists of each canvas component to be of identical length. Since there were 13 different text fields for the *TextCanvas* to account for all prompts, questions, intro and outro texts as well as the detailed answers. For the latter, there had to be different texts based on the answer given by the user. In case the user selected the correct answer, the answer text had to reflect that in the first sentence as a form of feedback. These cases required a specified value to be written into the current index instead of just advancing it to the next higher integer. Figure 10 shows how these connections finally looked in the visual node structure of LogiX. The connections shaded in light maroon connect to the *Counter* node to change the *ActiveIndex* value. While most buttons could make use of the "++" operator to advance to the next node, the special cases used integer value fields and the "write" action to change the index correctly.

Apart from having to adjust the index value for the entire quiz interaction, two buttons also needed to trigger the deletion of the object currently placed on the pedestal. These two actions occurred when the continue button was pressed after the user read the detailed information for each of the first two objects.

6.3.2 Pedestal Snapping

The pedestal in the middle of the starting room has an essential role in the concept of the interactive exhibition. Visitors needed to be able to let go of an object in its vicinity, which should then snap to the top of the pedestal and float there. While doing so, the object also needed to turn along its vertical axis to allow the visitor to look at it from all sides while trying to answer the quiz question. The text of the question as well as the buttons with possible answers needed to be activated by changing the index value mentioned previously. On top of these three actions, it also needed to be checked whether or not the object placed on the pedestal was the one, the visitors were currently

tasked to find. If that was not the case, the object needed to be destroyed and an error sound needed to play to signal to the user that they had made a mistake.

To implement all these functions, multiple components and node graphs had to be put in place. Initially, the function to have an object snap to the pedestal was implemented. To have an object snap to a certain point the object needs to have a component called *Snappable*. The object it is supposed to snap to, in this case, the pedestal, needs a component called *SnapTarget*. After both objects have been assigned these components, a reference between them needs to be created to specify which objects specifically are supposed to snap to the target. This was accomplished by using the tag label attached to all objects in NeosVR. By assigning the tag *Prop* to all objects that are part of the interaction, this could be accomplished in a way that was both quick and open for newly added objects. On the *SnapTarget* component of the pedestal, the tag was listed in the *SnapperKeywordWhitelist*-field to ensure the objects would snap to the pedestal. Additionally to using the tag to identify which object may snap to the pedestal, the distance from where they would snap once a user let go of them also needed to be specified. To use a larger area than the collider of the pedestal, a *SphereCollider* component was added with a specified radius of 3 units. This was a generous radius that would allow the user to let go of the object and have it snap to the pedestal from as far away as the entrance to the room of the quiz interaction. This large radius was chosen to reduce frustration among new users, but users still had the freedom to walk up close to the pedestal before letting go of the object in their hand as this action triggers the snap animation.

Since the items were supposed to levitate above the pedestal and also turn, all of the above was in fact not applied to the pedestal object directly, but to a child object of it. This empty and therefore invisible object did not only have the *SnapTarget* applied, but also a component called *Spinner*. This component allows a constant spinning motion along a specified axis. In this case, the vertical axis was used to neatly spin the objects around themselves at a moderate speed once they had snapped.

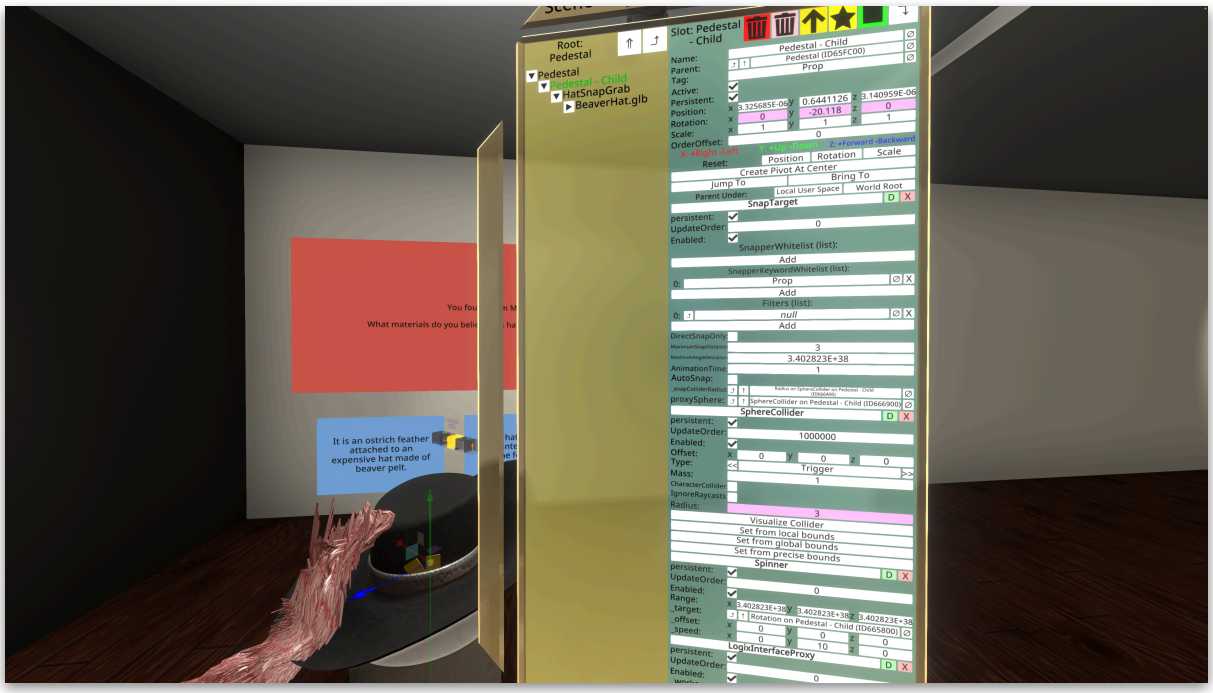

Figure 11: The Pedestal with the Hat Object Snapped

As it is visible in Figure 11, once an item snaps to an object with a *SnapTarget* component, it becomes a child object of the target. Besides the positive effect of moving the same way as that new parent object, this also comes with the pitfalls of scaling the child object the same way it is scaled itself. For this reason, all scaling values needed to be set to 1 for both sides. Since objects are being scaled on import in NeosVR and needed to be rescaled to fit their counterparts, a parent object was created that was scaled neutrally and contained the important *Snapper* and *Grabbable* components. The latter is needed to allow users to grab and carry the object.

6.3.3 Pedestal Connection

The names of these parental objects were then referenced in a graph of LogiX-nodes that was used to connect the pedestal interactions to the operational sequence of the quiz interface. In this graph, of which a large part is visible in Figure 11, multiple conditions are checked every time a new object is placed on the pedestal. Based on this check, there are two general outcomes. Either the object is destroyed and an error sound is played, or the quiz interface advances from the prompt text to the corresponding question section of the respective item. The former would occur if the name of the item on the pedestal and the index value of the corresponding prompt did not match the current *ActiveIndex* mentioned in the previous section on the functionality of the quiz interaction. On the other hand, the latter action would occur, if those values and names matched.

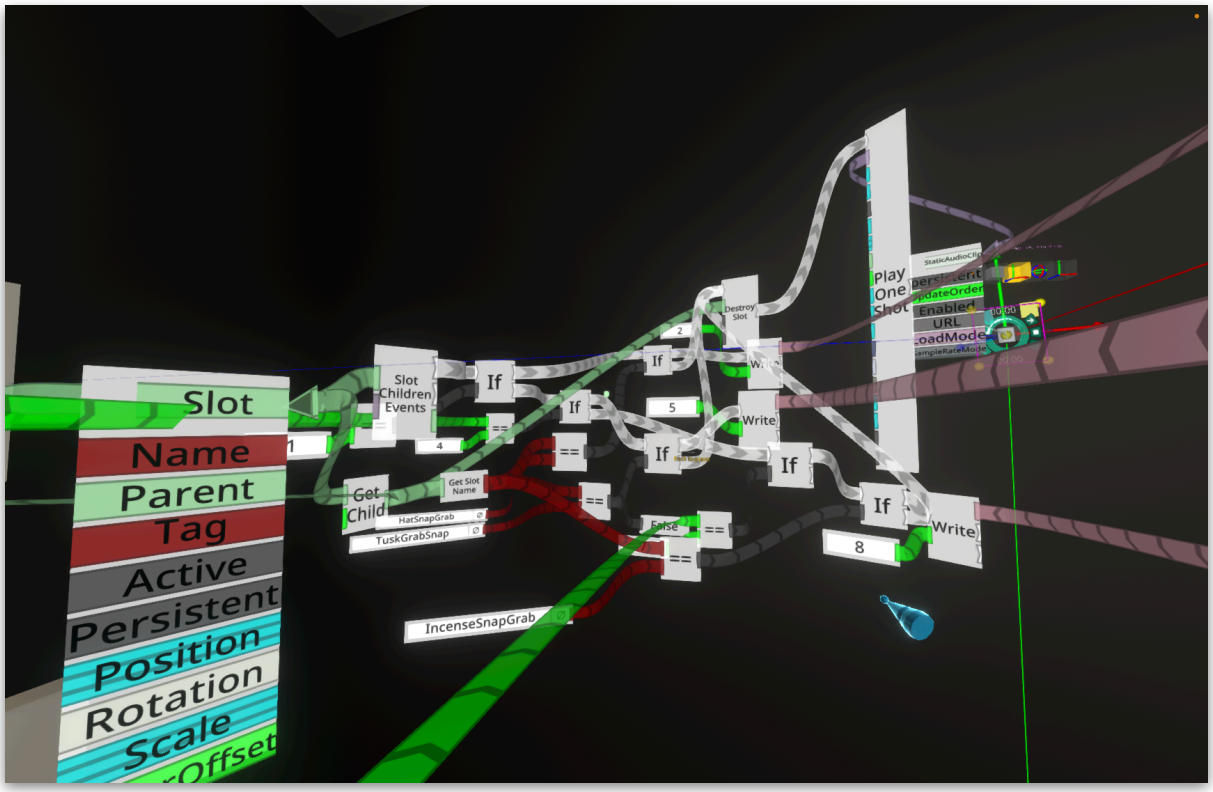

Figure 12: Graph of LogiX Nodes for the Object-based Quiz Progression

Various nodes have been used in this node graph. The most used ones are the “==“ operator as well as the *if*-node. An *if*-node in LogiX can take one impulse as an input as well as one condition, in this graph either an index value or the name of an object represented as a string. The node can check if the condition is currently true when it is being run. Running the function represented by the graph in

Figure 12 is caused by the impulse of the initial node of this tree, the *Slot Children Events* node. When a new child is added to the slot *Pedestal - Child*, in this case, an object, the first *if*-node is triggered. Each *if*-node has two possible outputs: true and false. Therefore, based on the evaluation of each condition, one of two possible nodes is triggered to run. For example, if the hat of Dom Miguel de Castro is placed on the pedestal, the first *if*-node checks the evaluation of the connected "=="-node. This node, in particular, evaluates to true, if and only if the current *ActiveIndex* or value of the *Counter* value field is exactly 1. 1 is the index for the prompt to find said hat. These evaluations work by using a fixed value field as well as the value field of the *Counter* object as inputs to the "=="-node. In case this node evaluates to "true", the "true" output of the *if*-node is triggered as well. This output is connected to yet another *if*-node, which checks the output of a "=="-node that compares two strings. One of which is a string field with the object name *HatSnapGrab* written in it. The other one is connected to the *Pedestal - Child* object with a *Get Child* node. This node returns the name of the first child object to the "=="-node. In the event that this object is the hat users are asked to find at quiz index 1, this string also reads *HatSnapGrab* and therefore, the node forwards a *true* output to the *if*-node. After these two steps, the last step in the function is to update the current *ActiveIndex*, by writing the according new index to the value field of the *Counter* object.

While this was the simplest progression of events in this function, the other options work in a similar manner. Whenever an *if*-node returns a *false* output, the function continues to the next alternative option. For the initial check of the current index before the check of the objects' names, this happens in a cascading manner. Each *false* output advances the function to check for the next possible index. On the other hand, if a name check evaluates to *false* the functions moves to the "destroy"-sequence. This entails that the object on the pedestal gets destroyed using the *Destroy Slot* node and the impulse of this node triggers an error sound to play once. While the error sound was implemented successfully, the sound that was supposed to be triggered in the event of a correct answer could unfortunately not be implemented in time before the start of the user tests. This is an unfortunate omission since it takes away a component of gamification that was meant to reward the users for their successful efforts. The implementation of this function should have been simple, however after using the *pack-in-place* tool to store all nodes away, the attempts to connect the rewarding sound, which had already been imported into the NeosVR environment, failed. Both sounds that were used for this prototype were found online and used under the creative commons license within this unpublished prototype [37, 38].

Even though this function could be optimised to rely on fixed values less, it is designed in such a way that it is open for additional objects, should they be added later. In that case, yet another pair of *if*-nodes would have to be added at the end of the current *if*-cascade.

6.3.3 Object Instantiation

As a final, yet basic, step to implement the concept with full functionality, the objects needed to be instantiated once a user grabbed the painted objects in the painting. To achieve this, an empty object was created on top of the paintings that were supposed to have interactive items. To this object, which was named after the item it instantiates, e.g. *HatSpawn*, two components were added to facilitate the interaction. First, a *BoxCollider* component was added over the area in which the user should be able to use the grab interaction to create the 3D instance of the painted object. The

boundaries of the *BoxCollider*, highlighted in magenta in figure 12, were defined with error margins in mind. This meant, that the user could be off by a few units in all 3 dimensions and still be able to instantiate the item by grabbing. For the same reason as the collider around the pedestal before, this was done to minimise frustration among less experienced users.

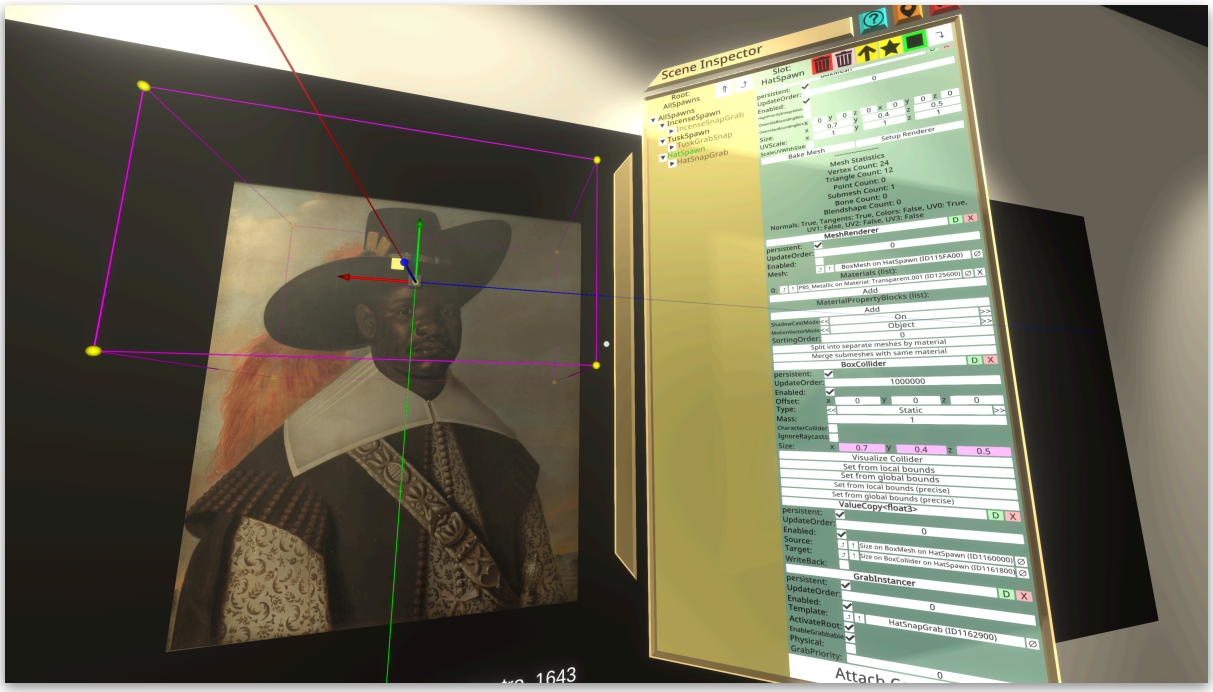

Figure 13: Object Instantiation using BoxCollider and GrabInstancer Components

In addition to the *BoxCollider* component, the *GrabInstancer* component was used to instantiate the item whenever the grab action is performed inside the collider of the *Spawn* object. This component uses a reference of the object as a template for each newly instantiated object. To make the 3D model of an object appear right above its painted counterpart, the template object was placed right there and was made a child of the *Spawn* object. This was necessary to enable the correct instantiation while the template could be set to inactive so that the template itself could not be moved and was not visible either.

Chapter 7: Evaluation

This chapter contains information on how the final prototype was tested and evaluated through a user test. Additionally, the results of this test are presented and preliminary conclusions regarding the setup and results are drawn.

7.1 Setup

To effectively evaluate to what extent users are benefiting from the aspect of being in a virtual museum space with another visitor compared to being on their own, a user study has to be designed accordingly. This user study needs to be set up in a manner that is suitable to help answer the defined research questions for this project. This project aims to evaluate three aspects of museum visits in virtual reality, namely the impact of a social experience compared to an individual experience on engagement, the impact of gamified interactions on engagement and lastly the impact that a multi-user experience in VR can have on the understanding of cultural heritage topics. To effectively conduct a user test with the prototype of the interactive exhibition within the given constraints of this project, a between-subject design for the user study was most applicable.

Figure 14: Multi-user Test Setup with Two Rooms

The participants were split into two equal groups. Half the participants entered the virtual environment on their own while the other half of the participants were in the virtual environment together with another participant they already knew previous to the test procedure. For this group, the two participants were placed in two different rooms and connected in the virtual world via the built-in voice communication channel in NeosVR. This feature also includes a spatially accurate representation of audio, meaning that participants of the test can identify where the other person is currently located when communicating. This spatial representation of audio is achieved through a change in volume based on distance as well as a directional representation through the speakers of the HMD worn by each participant.

The separate aspects that are part of the investigation were to be tested with one test procedure per participant that could provide sufficient insight without the need for additional groups or test procedures. This was important to achieve a sample size of $n \geqq 20$ across the two groups, which was set as a necessary minimum to allow for statistical evaluation with sufficient expressiveness.

7.2 Procedure

The procedure of the user study we conducted goes as follows:

1. Briefing using information letter
2. Obtaining informed consent
3. Setup of the virtual environment for the participant
4. Explanation of controls for locomotion, selection and grabbing
5. Participant tests the interactive exhibition without additional instructions[1]
6. Participant fills out a questionnaire with two sections
7. Interview with the participant
8. Debriefing involving offering a reward

This structure has been used for all participants of both groups. The time estimated for completing the whole test procedure is 30 minutes per participant with an expected deviation of up to 10 minutes. This rather large expected difference between test subjects is due to the fact that the exhibition leaves room for different styles of exploration as well as a difference in time taken for the following questionnaire and interview.

7.2.1 Briefing

During the briefing, the participants were asked to read the information letter, which can be found in Appendix D.2. Additionally, the most important aspects of the topic of the exhibition as well as the general purpose of the research were mentioned to them. Detailed information about the research questions was withheld intentionally to avoid introducing unnecessary bias.

7.2.2 Consent

Afterwards, the participants were asked to fill in the consent form provided in Appendix D.2. This consent form was composed primarily to obtain the necessary consent for this type of research. However, the more important practical aspect of the content forms is the question on risk awareness, in which participants are once more reminded about the risk of motion sickness that can occur as a side-effect of using HMD in a dynamic VR environment [29]. Additionally, participants are asked to consent to be recorded using a microphone and recording device during the concluding interview.

7.2.3 Virtual Environment Setup

Setting up the virtual environment required multiple steps involving the participants. At this point, participants were first asked their height. While the handedness was important for natural control inputs, the height setting in Neos VR was adjusted to ensure a correct representation of posture for the virtual avatar. The latter was chosen next by the researcher according to the basic

[1] instructions where given to participants that were confused about controls as well as participants that did not understand how to interact with the exhibition after a prolonged period of time

features of the participant's appearance. These primary features were hair and skin tone as well as the gender with which the participant identified. The avatar was then chosen from the set „Ready Player Me Humans“ avatar folder, which is available on the NeosVR platform as a public folder. This particular set of avatars was chosen because it provided a sufficient variety of appearances for human avatars. At the same time, it was also a convenient choice due to being available as a public set of assets to use on the platform. This made it possible to integrate human avatars as part of the test on user engagement within the time limitations of this project, which prohibited the creation of custom avatars.

After the height and avatar settings were completed by the researcher, the HMD as well as the controllers were cleaned using disinfecting wipes on all surfaces that come into contact with skin and then handed over to the participant. At this point, before handing the HMD to the test subject, they were asked about whether or not they have used a VR device before. Optionally, they were asked whether they are familiar with video game controllers. This was used to optimise the tutorial process for both participants with previous VR or gaming experience as well as those without.

Following this, the participants were instructed on how to adjust the HMD for improved visual clarity of the VR content as well as optimised comfort and were handed the device. If needed, participants received assistance to adjust the setting of the tightening wheels or straps on the HMD.

7.2.4 Tutorial

Once the participant received both controllers for the VR device, they were asked to clarify whether or not they were feeling any visual irregularities or physical discomfort. Subsequently, if everything appears to be in order, the controls to move around the virtual world, rotate the camera, select UI elements and grab objects were explained. The control mappings were set equally for all participants based on their handedness unless they expressed discomfort or concerns. The controls used were standard to the Neos VR program. The locomotion, which was set to walking in Neos VR, was handled with the thumb stick on the non-dominant hand while changing the first-person camera view was handled through lateral movement of the thumb stick on the dominant hand. Further, the interaction to grab objects was triggered by the button on the inside of each controller's handle, which is commonly referred to as the “grab button” by manufacturers. Lastly, the participants were informed that both trigger buttons, found at the top end of the controllers pointing away from the user's body, could be used to select objects in general and more specifically needed to be used to select buttons in the UI of the quiz interaction.

7.2.5 Test of the interactive exhibition

After completing the tutorial and ensuring there were no factors prohibiting the continuation of the procedure, participants were told to simply start exploring in their own time. They were specifically not given any further instructions on how to use the interactive components of the exhibition apart from the information they have been given in the previous sections of the user test. They were started in the room of the exhibition with the quiz interface in front of them. During the course of the test, they were not given additional instructions unless they expressed that they were stuck, had difficulties with the controls, technical performance issues or specifically asked about an interactive component of the exhibition.

During the entirety of this section of the study, a researcher was present in the room with each participant at all times. This allowed for a quick intervention in case of motion sickness or if the participant accidentally left the save boundary for using the VR headset. Additionally, the researcher could quickly help with issues as specified above.

7.2.6 Questionnaire

The questionnaire was used after the user test to evaluate the level of engagement for each user. To achieve a higher value of information for the evaluation, questions from two standardised and tested questionnaires were used. This resulted in a questionnaire that was split up into two sections. While both sections primarily test for engagement, the first section evaluates engagement and immersion specifically for VR experiences, while the second section was a more general questionnaire for engagement in games.

The test used in the first section was developed by Tcha-Tokey et al. [39] based on previous questionnaires on the sub-topics of engagement. While the whole test is meant as a complete questionnaire to measure user experience in immersive virtual worlds, a subset of questions relevant to the research question of this project was used. This subset consists of 16 questions measuring engagement and immersion and was originally part of a questionnaire on presence developed by Witmer and Singer [40].

To evaluate the questions, a 5-point Likert scale was used. The answer options were written in such a way that they made sense in the context of the question, but were still clearly identifiable with common operators such as “somewhat” or “very” in combination with either a positive or a negative statement to indicate the medium or respectively high level of agreement or disagreement on the Likert scale.

Equally, the second section of the questionnaire was scored using a 5-point Likert scale. The questions of this standardised test were posed in such a way that they could all be answered using equally phrased answer options for all of them, making them even more clear. This second set of questions was taken from the questionnaire on immersion in games, developed by Jennet et al [41]. To accommodate for the time constraints in place for the user test, only the 12 most applicable questions of that questionnaire were used, since the requirement set for the overall duration of the study was to stay within half an hour.

Additionally, to the 28 questions on engagement and immersion, 2 additional questions were asked at the beginning of the questionnaire. The participants were asked to indicate their age within a range of 3 years. Since this test was aimed to test with young adults the ranges started from 18 and went to 33. After this, a participant could indicate their age as >33, which would ultimately lead to the exclusion of their results for the evaluation. Apart from their age, participants were asked to indicate their biological sex. Answer options were therefore “male”, “female”, “other” and “prefer not to ask”, in case a person was not comfortable sharing this information. The biological sex was a subject of this questionnaire, because of the differences in susceptibility for motion sickness and discomfort based on biological sex with currently available VR devices[42]. The questionnaire thus included a total of 30 questions and was estimated to be completed within 7 to 10 minutes.

7.2.7 Interview

After successfully completing the questionnaire, the participants were asked to take a few minutes to answer a set of open questions in a face-to-face interview. For participants in the multi-user group of the user study, this interview was conducted separately in different rooms. This measure prevented participants from being biased by the answers of their peers in the interview. The interview was documented by the researcher during the interview by writing down the answers in a truthful but structured manner as well as by recording the conversation. This recording has later been transcribed to identify any information that has not been captured in the notes. Having this redundancy in place to capture the answers to the interview questions ensured that this data could not be fully lost due to technical failures or human errors.

There are two main reasons for conducting this interview as a final main component of the user tests. Primarily, an interview with open questions can help answer the research questions. This can be achieved by carefully analysing the given answers within their context or by using the answers to draw conclusions from the statistical analysis of the questionnaire. The latter can be especially relevant for user studies with a limited number of participants, which is applicable to this study. Additionally, asking participants about issues that could have impacted their ratings on the questionnaire can help with interpreting those results.

Based on the previous intentions, a set of 14 questions was defined. The full list of interview questions can be found in Appendix D.3. While 11 of those questions were posed to all participants, the remaining 3 were exclusively meant for those test users that tested the exhibition in the multiplayer setting.

The majority of interview questions were designed to evaluate the visitor's experience with a focus on the impact of the separate components on both user engagement as well as the understanding of the cultural content of the exhibition. The latter was not previously evaluated by the standardised questionnaires, which is why the results from these answers were especially important to answer the corresponding sub-question of the research. Additionally, there were questions about the perceived impact of the virtual avatar and the perceived impact of communication between visitors for those that tested the multiplayer version of the exhibition.

7.2.8 Debriefing

To conclude the user testing for the participant as well as the researcher, the participant was given an opportunity to voice any final concerns or comments. Likewise, they had the option to revoke their consent. Within this concluding conversation, open questions that could not be answered during the main phase of the testing were answered by the researcher. These included questions about the exhibition and the research that were not answered to avoid introducing bias. Finally, participants of the user study were thanked for their time and given a sweet treat of their choice from a small selection.

7.3 Execution

7.3.1 Pilot test

After defining the test procedure as specified previously, the prototype of the interactive exhibition was pilot tested. This included a full test run of both the test of the exhibition as well as the questionnaire and interview part. The main reason for this pilot test was to find a good benchmark in terms of the time needed for actual user testing. During the specification of the test procedure, the initial estimates for the time needed to complete one user test were between 45 and 60 minutes. This would have been too much time for most potential participants to spend on such a test, which is why certain aspects of the prototype, as well as the interview and questionnaire, were reduced in complexity to shorten the process.

The pilot test showed that all components were working as intended and the process should take about 30 minutes to complete.

7.3.1 Recruitment

Based on the pilot test, potential participants were invited to test the interactive exhibition with an expected duration of 30 minutes. Since potential participants were all those people that are less than 30 years old and able to use virtual reality devices without experiencing negative effects on their health, the invitations were primarily directed towards university students.

The recruitment process involved three phases: Initially a digital poster was produced and posted to multiple chat groups of university students, reaching around 1000 potential participants. The poster was accompanied by a written invitation that contained a link to an online form in which participants could indicate their availability. Unfortunately, few people signed up through this method. Because of this, an adjusted version of the poster was made and printed out. This printed version contained a QR code that linked to the same form and was posted to various bulletin boards and left on tables in common areas. Both versions of the poster can be found in Appendix D.1.

Finally, over half the test subjects were recruited by directly talking to potential participants on campus. This method also yielded the highest rate of success across the three methods. In total 21 participants were recruited, of which one ended up being too old for their results to be considered for the evaluation of the test. The other 20 participants ranged in ages between 18 and 29 with a majority being between 18 and 21 years old.

The recruitment process as well as the design and distribution of posters was completed in collaboration with Lisemijn Presser who worked on a project with the same exhibition, “HERE: Black in Rembrandt's Time”, at its foundation.

7.3.1 Tests

The actual user tests were conducted in two rooms within the facilities of the University of Twente. The two rooms were adjacent and had glass walls, which allowed cross-monitoring of other participants during multi-user testing but also prevented sounds from passing between rooms. The latter was important to allow users to accurately experience the spatial representation of each other's voices in the virtual space. For multi-user tests, an assisting researcher was present in the other room.

The hardware used during the tests varied between the different testing days since the desired devices were in high demand at the. This was due to the fact that all equipment was borrowed from the Interaction Lab as well as the BMS lab at the University of Twente.

The PCs that were used were Lenovo Legion and Thinkpad Laptops, running Windows 10 and 11 respectively. Connected to these laptops, a variety of VR headsets were used. Most tests were performed using the Meta Quest Pro, which arguably is not the ideal VR headset due to its open design around the eyes. This allowed for more peripheral vision than a typical VR headset. Using this HMD could however not be avoided due to the lack of availability of other options. Additionally, the Meta Quest 2 HMD was used as well as the HP Reverb G2. While these devices provide a lower resolution compared to the Meta Quest Pro they are built for higher immersion with a closed design.

During the tests, the hardware mentioned above occasionally caused delays or slow performance in the virtual environment. Additionally, some participants complained about the resolution and therefore low readability of text in the virtual environment. Apart from these technical difficulties, the tests have been conducted without interruption.

7.4 Evaluation Results

7.4.1 Results of the Observations

As described previously, the researchers made short notes on the behaviour of each participant during the user test. The main point in making these notes was to document irregularities that could have an impact on the participant's answers on the questionnaire as well as during the interview. However, behaviour patterns that could be indicative of the participant's understanding of the contents of the exhibition or engagement during the test, were also noted.

Evaluating these notes, which can be found in Appendix D.4, gave multiple insights. For example, 15 out of the 20 total participants showed great interest in the content of the quiz. They showed this interest by taking their time and contemplating which answer might be correct and then also taking their time to read through the entire paragraph of information provided to them after answering. The same behaviour could not be observed for the texts placed next to the paintings, even though those were shorter individually.

Another frequent observation was that participants would have some trouble controlling their movement and camera position in the virtual environment. For most participants, this behaviour occurred less towards the end of their test and primarily during the first one to three minutes after starting their test. On the contrary, the observation that participants had no trouble with the controls of the grab interaction was noted multiple times, especially for the interactions with the second and third objects during the experience. In addition to this, a common behaviour observed among participants was that the later objects that were asked for in the quiz were found very quickly in comparison to the first one.

Besides having some trouble with the, often unfamiliar, controls of VR devices, eight participants, almost half, had some type of issue related to the hardware. Most frequently, the NeosVR environment would freeze or lag for a moment while users were grabbing an object. This occurred most frequently with the hat object, which was the most complex in terms of the number of polygons. Other than that, some participants using the HP Reverb G2 HMD complained about the fact that the

hands of their virtual avatars were crossed or moving erratically. Another issue that was brought up by the participants was the fact that the resolution of the various HMDs in use during testing did not suffice to produce readable text at a regular distance. Despite using a larger text size on the quiz canvas, some participants had trouble reading these texts. Furthermore, words used in the prompts for the quiz, such as “pompous” but also “hunting trophy” caused visible or audible confusion among some participants that did not have a clear concept of the meaning of these words.

Comparing the two groups of participants, some more significant observations regarding the experience were made. For one, participants that were part of the multi-user group, except for one pair of users, worked together to find the answers to quiz questions. Three groups of two participants actively talked about the different options that were presented to them as answers, while another group just briefly discussed them starting with the second quiz question. One group did not show interest in discussing the questions or answers to the quiz and seemingly preferred to read the content on their own without making conversation.

Generally, the participants of the multi-user group seemed to spend more time pondering what option could be the correct one, while participants of the other group quickly decided on their own. In the context of the quiz interaction, it was observed that for two multi-user pairs of participants, one of the two would skip the answer to a question or select an option without waiting for the other participants. This was met with expressions of displeasure from the participants that therefore did not have the opportunity to make a guess or read the information. Similarly, a few participants of the multi-user group were observed to be disappointed when they learned that the pedestal could only hold one object at a time. This was usually the case, when both participants had instantiated an object and took it to the pedestal. Only the first object would snap to it while the object held by the other participant would just float in front of them, which appeared to disappoint them.

7.4.2 Results of the Questionnaire

To evaluate the questionnaire an array of statistical analyses have been conducted. To prepare the captured data from the questionnaire to be used in the statistics software SPSS, it was first coded in Microsoft Excel. The data was downloaded from the Microsoft Forms online tool that was used to collect the answers to the questionnaire, which led to the answers being coded as written text in accordance with the Likert scale items. The answers were coded from 0 to 5, with 5 being the highest valuation on the scale and 0 being the lowest. For the second section of the questionnaire, four questions were inversely coded. This meant, that the answers had to be reversed, e.g. a score of 1 would be coded as a score of 5.

After preparing the data, it was imported to SPSS Statistics, version 28.0.1.0. In SPSS, the variables for the groups were named “single” for the single-user group as well as “coop”, as in cooperative, for the multi-user group. To see the difference in scores between the two groups across the two sections of the questionnaire, the mean scores were compared.

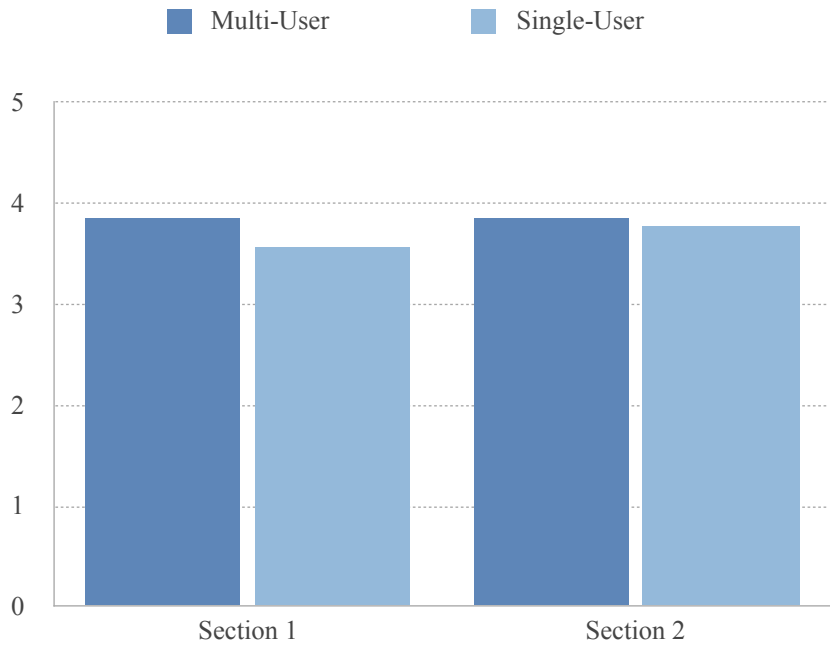

Figure 15: Comparison of Mean Scores between Groups

As demonstrated in Figure 14, the mean scores of both groups across both questionnaires are quite similar. The multi-user group scored slightly higher than the one of the other group in both sections, while the scores of both groups have their mean slightly below a level 4 on the 5-point Likert scale.

To evaluate the expressiveness of these results, the internal reliability of the two sections of the questionnaires was tested. All tables produced in SPSS can be found in Appendix D.5. To test internal reliability, the Cronbach's alpha value for the different sections of the questionnaire and user groups were evaluated. Cronbach's alpha is used in statistics as an indication of the expressiveness of a questionnaire. The alpha ranges between 0 and 1, with higher values indicating higher internal reliability. While there are no definitive rules to the cutoff points between different levels of expressiveness, an alpha of 0.7 is commonly referred to as good internal reliability for a questionnaire. Lower values can be acceptable, however, they indicate that questions within the questionnaire may not be interrelated well enough to assume the results of the questionnaire are statistically expressive.

For the first set of questions on engagement in virtual reality environments, the raw Cronbach's alpha value across the two groups was 0.664. The alpha for the multi-user group alone was higher at 0.698 while the alpha for the single-user group was lower, at 0.570. The second set of questions, taken from the game experience questionnaire [41], showed an even larger divide between alpha values. The joined alpha was evaluated to be 0.526, while the multi-user group scored at 0.729 and the single-user group at a low value of 0.300.

Population	All	Multi-User Group	Single-User Group
Section 1	.664	.698	.570
Section 2	.526	.729	.300

Table 1: Cronbach's Alpha Values

These values, as shown in Table 1, vary greatly from one another. However, the reliability scores for the answers of the multi-user group are at a good level. This is significant since this evaluation as a whole mainly seeks to evaluate the engagement of users in an SVR setting. Still, the low internal reliability scores for the single-user group needed to be investigated to allow for a fair comparison between the two groups.

When investigating this, two reasons for the low score became apparent in the case of the single-user group and the first section. SPSS excluded question 7 entirely since there was no variance present in the answers at all. This is due to the unlikely event that all 10 participants have given the same score to the item. This exclusion negatively impacts the score. Additionally, when looking at the items that have the largest negative impact on the alpha value, question 16 is listed. Unfortunately, nothing unusual about the phrasing or the scoring of this question could be found.

Investigating the reason for the low consistency in the second section for the single-user group did not hint at any specific questions being out of line, but rather at a general issue. Since the questions about immersion appeared to be applicable to both the single-user as well as the multi-user group, investigating this statistical score alone was inconclusive.

To further compare the means of both sections of the questionnaire, the distribution of the datasets was investigated. The assumption was that the dataset for both groups divided over both individual sections of the questionnaire was normally distributed. To test this, the mean scores per person were tested in a Shapiro-Wilk test, which is applicable to test the normal distribution of a dataset with a small number of subjects n ($n<50$). A table containing the results generated in SPSS can be found in Appendix D.5. Based on the critical value of significance at 0.05, resulting in a standard confidence interval of 95%, the results for both sections and groups were interpreted as normally distributed. Due to this circumstance, a two-sided t-test on independent samples was conducted to further compare the means of the two groups. The null hypothesis H0 for this test was that there is no statistically significant difference between the means of the two groups of subjects for both sections of the questionnaire. The alternative hypothesis for the test was that the means between the single-user and the multi-user groups are different for one or both sections of the questionnaire. With a confidence interval of 95% and a corresponding alpha of 5% or 2.5% per side, the null hypothesis could not be rejected for either section of the questionnaire. Therefore, the means of both groups can not be considered significantly different based on the statistical analysis.

Because the result of the t-test, as well as the varying evaluations of reliability, the datasets were further investigated, by looking at differences in means per individual item on the questionnaire. This was done, to find hints towards potentially significant differences between the two groups of participants. Two separate types of insights were gained. For one, only three items across the two sections of the questionnaire showed significant differences in their means based on a t-test. Additionally, three more items across the two sections showed atypically low values across the two groups. The latter observation was made for three questions concerning the control devices as well as the HMD in use and its impact on the user's susceptibility to outside influences. The former three questions, questions 5 and 11 on the first as well as section 6 on the second section, provided more impactful insights. These questions showed significant differences between means, based on their p-value on an according t-test, which can be found in Appendix D.5. Question 11 can be disregarded for

any further analysis regarding its significance to the immersion and engagement of the users. This is because it is about the ability to localise sounds, of which only one was present for participants of the single-user group, while the other participants had the opportunity to communicate with spatially accurate voice chat, explaining this result. Finally, questions 5 of section 1 and 6 of section 2 are contradicting the remaining findings, as they would give evidence that single-user participants felt less involved by the visual aspects of the virtual world and that multi-user participants felt events taking place around them more than participants of the other group.

After this final test of the datasets, the statistical analysis of the data was concluded. The statistical findings show that while the datasets can be considered mostly reliable as well as normally distributed, there is no statistical evidence for a higher level of engagement based on either section of the questionnaire between the single-user and multi-user groups.

7.4.3 Results of the Interviews

The interview, conducted as the last step of the user study, provided insights into the way the participants perceived the experience themselves. Almost all participants felt that the interaction with the objects was the most striking and, for some, surprising element. Some others mentioned that the quiz stood out to them more and two participants stated other elements of the interaction to be most memorable. In connection to the actual educational topic, however, only a few participants stated that they had actually learned something that was interesting to them or changed their view on the cultural heritage presented in the exhibition “HERE: Black in Rembrandt’s Time”. Still, participants of both groups equally stated that the interactions with the quiz and the objects made them think about what they were doing and what they were looking at more. Some mentioned that they read the descriptive texts next to the paintings or look for details in them, which they stated they would not have done otherwise. The same was said about the answer texts provided in the quiz. While some mentioned not having read them, others said they read them only because they were intrigued about the story at that point after they had to think about it during the quiz.

Contrary to the questions about the educational contents of the exhibition, when asked about the elements of gamification, the participants enthusiastically answered what they enjoyed about the interactive elements. They mentioned that they enjoyed the details of the 3D models, the fact that they could turn them any way they wanted to and also the way they moved on the pedestal. Especially in comparison to a physical museum space, the participants positively noted a plethora of possibilities that come with the virtual space. For example, moving around quickly to look back at an exhibition that one has already passed, or the lack of a necessity to be quiet. In a similar fashion, multiple participants of the multi-user group mentioned that being in VR alone or just with a friend removed the serious atmosphere that they typically felt to be present in a museum. For some, this also led to a lack of focus on the content of the exhibition, since they felt more involved in the mechanics of the gamification.

Apart from the questions about the contents, participants were also asked about the way they felt about having an avatar. For participants of the single-user group, this barely seemed to impact the experience as they would only see their arms occasionally, while the multi-user participants stated a great effect of having an avatar. While both groups mentioned that sometimes technical difficulties as well as the limited selection of avatars took away from the experience and their immersion,

participants from the multi-user group stated that the avatar made them feel, like they were “together in the room”.

Finally, questions about wearing the HMD as well as using NeosVR, revealed what had previously been observed during the test. Seven participants stated that the weight, temperature or resolution of the HMD impacted their comfort and immersion while using it. Additionally, seven more participants stated that wearing the Meta Quest Pro specifically caused them to lose their feeling of immersion, due to the peripheral vision it enables. However, one of these participants described it as a positive aspect as well, since for them it removed the feeling of motion sickness they typically encounter. This widespread issue that is particularly common among first-time VR users was listed by only two participants that mentioned starting to feel slightly dizzy or experiencing a headache towards the end of their user test.

Chapter 8: Discussion

In this chapter, the final design of the interactive exhibition as well as the result of the evaluations will be discussed. To do so, the merits as well as the shortcomings of the prototype with respect to the execution of the different design phases as well as the evaluation will be examined. Recommendations for future projects will be stated.

Based on this discussion in terms of the quality of the research process and final prototype, the findings will be used in Chapter 10 to draw conclusions to the research questions posed at the beginning of the report.

Reflecting on the final design of the interactive exhibition, multiple limitations need to be discussed to put the findings of the user test into perspective and derive plausible interpretations. While, in general, the prototype that was used for user testing was complete and ready for a test procedure, it was primarily limited in terms of complexity.

For one, only three objects and subsequently three sections for the quiz were implemented. While this was sufficient to conduct a user test, it may have limited participants in their ability to further explore the interactive components in the virtual exhibition. This was reflected in the results of the observations, as some participants did not need to continue exploring after completing the first question and instead obtained the next object using a direct path. This shortened the time spend on exploration, which may have negatively affected the levels of engagement.

Apart from the complexity in terms of the length of the interactive experience, only a few moments of feedback have been implemented in the final prototype. In the case of auditory feedback, the sound effect indicating a successful answer or input by the user with regard to the quiz was not implemented. This omission took away an element of immersion and gamification, which was later reflected through the scores of the according items on the questionnaire. Other than that, there was little feedback connected to the visitor's performance on the quiz. While this was intentional to not turn the rather serious topic of the exhibition into a game, it reduces the presence of elements of gamification. This in turn may have had a negative impact on the overall engagement of users. On the topic of interactivity, the results of the observations and interview show that the final design provides a level of complexity that is manageable for new users within a short period of adjustment, given correct technical functionality of the system.

Lastly, the final design of the interactive exhibition does not allow for parallel interaction with the quiz. This led to misunderstandings and moments of disappointment that were observed among users of the multi-user group.

Apart from the limitations of the design of the prototype that were caused by the time constraints as well as the execution of the different design phases, the evaluation in the form of the user test was also limited both in scope and by technical modalities. The latter limitations were introduced by the lack of availability and the state of current-generation HMDs. Among the multiple different devices that have been used, none provided a perfectly stable and smooth experience for all participants. Similarly, the PC hardware in use caused lags in the Neos VR environment. This had an

impact on the immersion and overall experience of the participants, which was reflected in lower and less consistent scores on the concerned questionnaire items as well as statements made during the interview. The evaluation was also limited in overall scope. 20 participants and the goal to stay within 30 minutes per test was deemed acceptable for the overall procedure but did not yield statistically significant results. Furthermore, the questionnaires used for the statistical evaluation were shortened compared to the versions made in the research they were proposed in. The applicability of the questionnaires used may be limited as well since they focus on immersion as a part of engagement but lack items about other areas such as the social components of engagement. Additionally, while the participants satisfied the requirements for the age of the target group, the diversity in backgrounds was limited, since all participants were researchers or students at the University of Twente. Therefore the population of the user test was less diverse and more likely to have a background in technology and knowledge concerning the use of VR compared to the defined target audience. Additionally, university students may generally be considered to have a background in higher education, potentially impacting their interest and knowledge about the exhibition.

Despite these limitations of the design and the evaluation, the results of the evaluation show that the design provided an applicable solution for an engaging experience. This is reflected in all three forms of evaluation that have been used in user testing. The observations made during the testing demonstrate that participants of the multi-user group were actively collaborating on the interactive element by discussing their approach to answering the quiz questions. This can be seen as a sign of engagement according to the definitions used to define the engagement in the scope of this project. Additionally, the general scores on the questionnaire across the two groups were in favour of an immersive and therefore engaging experience and also indicated a benefit of employing an interactive exhibition as a multi-user experience over a single-user one. The further comparison between the two groups is however limited by the statistically insignificant difference in means between the groups for both sections of the questionnaire. Still, when investigating the scores of individual items, the engagement caused by the gamified design of the exhibition was high, but the overall scores were lowered due to the technical issues experienced by the participants.

The findings of the interview show that the participants felt more interested and engaged in learning about the heritage presented in the exhibition, showing that an engaging experience can be useful for educational purposes. The perceived understanding of users showed to be improved due to the quiz, as users reported that they felt more inclined to think about the topic to solve the question. Based on the combined findings of the observations and the interview, the interactive elements require visitors of the exhibition to think about what they are seeing when typically they would not do so at all while gazing at pieces of art they do not know anything about.

Furthermore, the results show that providing an avatar to users increases their feeling of presence and therefore their engagement. In addition, it helps with navigating the game world by using it as a point of reference for the position of another visitor.

To summarise the discussion of the design and test procedure it can be stated that the prototype fulfilled its primary purpose to be used for user testing to find whether or not this type of solution can

be applicable for art and history museums. For future work, however, several recommendations can be made to improve the clarity as well as the quality of the results of the test procedure. Before conducting another round of user tests, certain key components of the design should be completed and improved. For example, components such as the feedback sounds, should be implemented correctly as specified in the final concept of the design. Implementing additional auditory feedback could also be advisable. Equally, the number of interactive objects could be increased in future iterations to facilitate a longer experience that provides additional options for exploration to the users. A design featuring the possibility for parallel interaction for both users should be considered as well. Furthermore, the questionnaires used to evaluate engagement would need to be adjusted for more expressive results. This also entails using additional or more suitable questionnaires, but also using more or even all items of each original questionnaire in a more lengthy user study with more participants for a higher expressiveness of the statistical evaluation.

To make sure, no unwanted negative bias is introduced, all participants should use the same VR device, preferably one that combines a closed design with high-resolution displays. The most fitting device for these criteria that was also used in this research is the Meta Quest 2, even though the display resolution was still not ideal for reading text elements. Using avatars that are matching the user more accurately may also increase the presence of users in a social VR experience.

Finally, as for the general future of social virtual reality in the museum, the approach of using elements of gamification and leveraging the social drive of many visitors appears to be a good start to work on new designs for other exhibitions. While using an exact copy of the real exhibition may not be enough to excite visitors, even simple elements of gamification can animate users to entertain each other and themselves while learning about new topics in the museum.

Chapter 9: Conclusions

To conclude this report, the final remarks concerning the questions posed at the starting point of this project can be stated. This is done by drawing conclusions based on the findings and limitations in the discussion and by connecting them to the research questions.

The interactive experience of the exhibition “HERE: Black in Rembrandt’s Time” provides young people with an educational and entertaining way to visit an art museum. The findings of this research project show that the elements of gamification, namely the search of objects as well as the connected quiz, make the experience engaging for young people. The evaluation shows that the experience facilitates sustained engagement for individual users as well as pairs of two users.

While the statistical analysis provided limited significant results, the qualitative analysis of the interview and observations show that users of the social virtual reality experience are socially engaged with one another as well as the exhibition. This also results in a higher level of attention toward the educational contents of the quiz by enabling discussion on the topic. In connection with the remaining findings, this allows for the conclusion that users benefit from the social aspect in terms of their gain of knowledge and understanding of the cultural heritage topic presented in the exhibition “HERE: Black in Rembrandts Time”.

Using these conclusions, the research questions can be answered in the following ways:

Primary RQ: To what extent can social virtual reality exhibitions improve engagement among young museum visitors?

This research shows that virtual reality experiences may generally be applicable to facilitate engagement among young visitors. Introducing a social aspect further improves engagement by providing additional and natural interactivity without introducing disengaging complexity. However, further research is required to find statistically reliable evidence.

Sub-RQ 1: What is the impact of interactions with elements of gamification on user engagement in virtual reality?

The gamified experience provides users with a way to be more deeply involved with the exhibits. The elements of gamification strongly impact the engagement by producing interactivity, immersion and involvement with the experience. In a social VR experience, elements of gamification can also contribute to engagement by facilitating social connections.

Sub-RQ 2: How can a multi-user experience improve the understanding of cultural heritage topics in an art exhibition in SVR?

By employing a quiz as an element of gamification, discussion and exchange of information can be facilitated between users which may improve the understanding of the cultural topics of an art exhibition. Further research is needed to determine the extent of this effect.

This research project has shown how social virtual reality can be used to create more engaging art exhibitions to help museums reach younger audiences better. While more research is necessary to evaluate the true extent of this discovery, the findings of this project can be used as a starting point.

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Appendix A - Ideation

1. A floating label that appears when a visitor points at a painting and presses a button

With current VR hardware, the original label next to the paintings is very difficult to read at a typical distance between visitors and paintings. Allowing visitors to gain more information when they want to without compromising their view of the painting would help with this. The interaction would be simplistic and accessible for all types of users, may however not provide a good basis for social interaction and should therefore only be considered as an addition for usability.

2. When looking at a painting, a question for discussion appears above it

This method would allow users to gradually learn more about the painting. At first, they may see the painting, make up their own mind and after a specified amount of time, a question appears, which can either be discussed with a human guide in the virtual environment or another visitor. These questions could be phrased in a way that visitors need to take a second look at the painting and figure out some details themselves first, before eventually an explanation may be displayed or given by a guide. Questions could regard the objects, clothes and other details in the painting and lead visitors to discuss their potential meanings with each other. They could also be used to spark conversation about the stories of the actual people that are depicted in the paintings. Questions about their social status and profession may not always be easy to answer but may facilitate an important learning moment within the context of the exhibition.

3. Paintings with animated characters

Immersion is one of the three key factors for engagement. Making the virtual environment become alive, even if it is just in the slightest of ways, may drastically improve the level of immersion that visitors feel. Therefore, having the persons in the painting move, even if it is just a small amount, could lead to more interest in their stories. This idea may face issues regarding the historical accuracy and intent of the curator, which is why extensive research would have to be done to find a permissible way of implementation. It should also not distract from the still image of the painting, so it should either only be an active feature while a visitor is not yet actively looking at a painting or should only become active by means of user input. Still, animated characters that could potentially deliver additional information with speech bubbles or voice lines, may be worth considering to increase immersion.

4. Prompt visitors to search for an object in one of the paintings, take a 3D object out of the painting and return to get more info.

In a central place of the exhibition, a hovering prompt could send visitors on a small treasure hunt around the exhibition, facilitating a more free, explorative interaction with the game world while giving the incentive of gaining information of educational value. The prompt could give visitors the task to search for an object together that can be found as a detail in one of the many paintings. This object could then be collected as a 3D object and brought back to the central area in which the prompt is located. Once brought back, one or multiple follow-up questions about the object may be displayed. This could act as an interesting quiz that the visitors have to solve. Finally, all relevant information about the object may be revealed either as answers to the quiz, a final piece of text or the explanation of a guide. This interaction may have a better impact on engagement in a social VR setting compared to a setting with only one visitor since searches in an unknown environment are something that is generally more interesting and fun as a group activity.

5. Shapes containing symbols for more information after looking at a painting for a longer

After getting an initial idea of what the painting depicts, a visitor might quickly want to find out more about the story behind it. Therefore, shapes, such as bubbles, could appear in an animated style around the painting after a certain amount of time of standing in front of it. This interaction is simplistic but can provide certain information such as painting style, profession of the depicted person or more information by means of symbols that are easy to understand at a glance.

6. Adding the ability to pick up a painting and walk with it

Allowing visitors to “touch” the paintings, something that would be unimaginable in the real world, could provide a deeper connection between the visitors and the paintings while using the potential of the virtual world. Visitors could pick up a painting for closer inspection or take it with them to show to another visitor or compare side-by-side with a different artwork. It should be noted, that for this interaction to be permissible the painting would have to immediately return to the original position determined by the curator once it is no longer needed by the visitor.

7. Symbol-based quiz for simple information about paintings

To make learning about the paintings and the persons in them more engaging, interaction and gamification can be useful tools. For this implementation, empty circles around each painting would have to be filled with the correct symbols that correspond to information about the painting and the story of the person. The symbol can be dragged using the controllers and snap in place when they are placed correctly. This allows for an interactive learning experience that also encourages visitors to think on their own or collaborate with their peers.

8. Starting visitors on different ends of the exhibition

When starting the exhibition visit, two visitors that want to see the museum together may be placed at different ends of the virtual world initially. After finding each other, they can both already have a conversation about what they have seen so far and commonly decide where to go next. While not interaction in itself, this method could facilitate social interaction without adding complex control schemes.

9. Changing the environment around the painting by user input

To allow for a high level of immersion and understanding of the story behind the persons in the paintings, visitors may find themselves in a truly immersive environment that represents the place where the person in the painting may have lived. This change in environment could be triggered by pressing a button next to the painting. The new environment would still contain the original picture in the centre, but around it, the street, house or area in which the depicted person has lived is shown in a fully 3D model. This could help visitors understand the living conditions in past times and spark some additional interest to explore the details of that new world.

10. Search Activity within the changed environment

Based on the previous idea, it could be an option to stimulate exploration by setting up a small search game within the new environment. The visitors would then be prompted to search for the person in the picture in the new environment around it.

Due to concerns about historical accuracy and feasibility, this environment should be static and all elements well-researched to avoid misinformation.

Appendix B - Specification

Component	Description	Type	Priority
3D Models	≧3 Models	Functional	Must
3D Models	Instantiation & Grabbing	Functional	Must
3D Models	Detailed Models	Non-Functional	Should
Pedestal	Snap & Hover object	Functional	Must
Pedestal	Detect & Match Snapped Object to Quiz	Functional	Must
Quiz	Display prompts, questions, answers	Functional	Must
Quiz	≧1 question and detailed answer per object	Functional	Must
Quiz	Multiple rounds of questions per object	Functional	Could
Quiz	Educational & Entertaining Content	Non-Functional	Must
Quiz	Treat heritage & intentions respectfully	Non-Functional	Must
Buttons	Button interaction, answer options, continue	Functional	Must
Movement	Ability to explore freely, locomotion & view	Functional	Must
System	Multiple users in the virtual world	Functional	Must
Feedback	Failure & Success sound effects	Non-Functional	Should
Avatar	Avatar matching the user	Non-Functional	Should
Motion Sickness	Snap-Turning/other mo-sickness mitigation	Non-Functional	Should

Table 2: MoSCoW Analysis of Requirements

Appendix C - Realisation

	Name	Object A	Meaning	Object B	Meaning	Year
A1	Two African Men	White Scarf	Regular Clothing			1661
B1	Market in Dam Square					1653
B2	Head of a Boy					Ca. 1660-65
B3	Map of Pernambuco					1665
A2	King Caspar	Incense Jar	Gift, Medicine., wealth	Red jewel	wealth	1654
A3	Head of a Boy in a Turban (Tronie)	Feather/ Turban	Mediterranean fashion	Blue fantasy costume	Not a historically accurate figure	1635
A4	Man in a Turban	Feather/ Turban	Mediterranean fashion	Red robes	Unclear if representative	Ca. 1627-29
A5	Portrait of Dom Miguel de Castro	Hat w/ red feather	Power, traveller/ tradesman	Silver belt	Wealth	1643
A6	Portrait of Diego Bemba	Gold box	Diplomatic gift			1643
A7	Portrait of Pedro Sunda	Elephant tusk	Export of ivory			1643
A8	Three portraits of a boy, a Girl nd a Woman	Middle class clothing	Typical citizen			1645
A9	Portrait of a Man					1660-75
C1	Hermina Huiswoud					2019
C2	Ilona					2019
C3	The Unspoken Truth					2019
C4	Doritos	Bag of chips	Modern/ irrelevant			2019

Table 3: Paintings and Usable Objects and their Meanings

Figure 16: Model of the Golden Incense Jar in the Neos VR environment

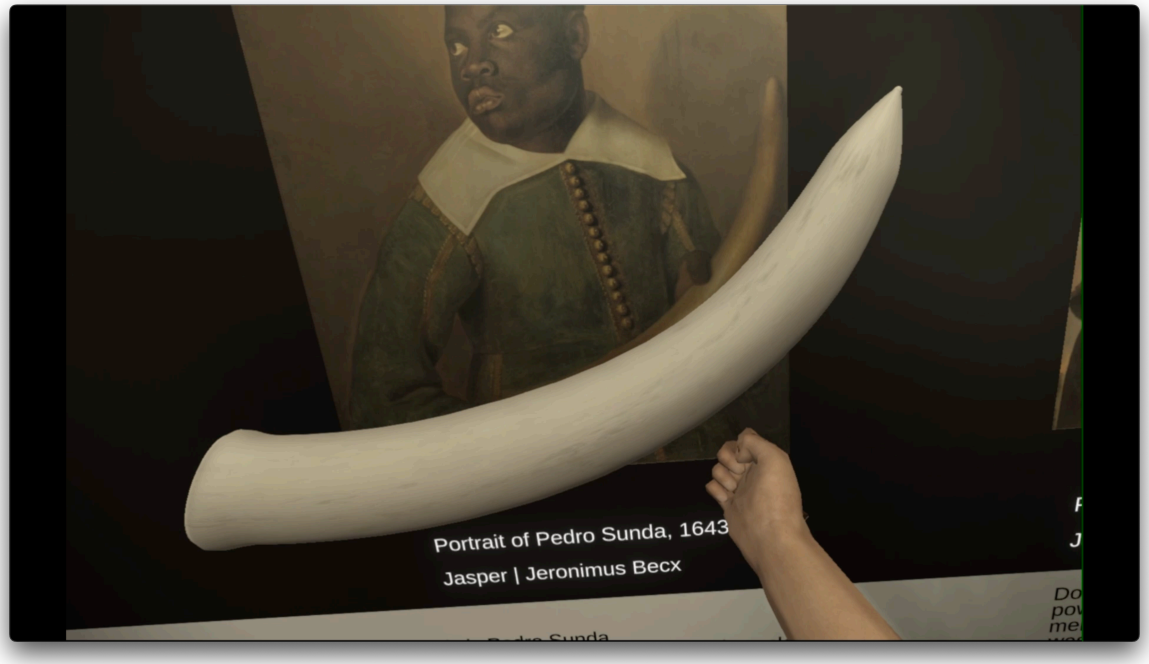

Figure 17: Model of the Elephant Tusk in the Neos VR environment

Appendix D - Evaluation

D.1 - Recruitment posters

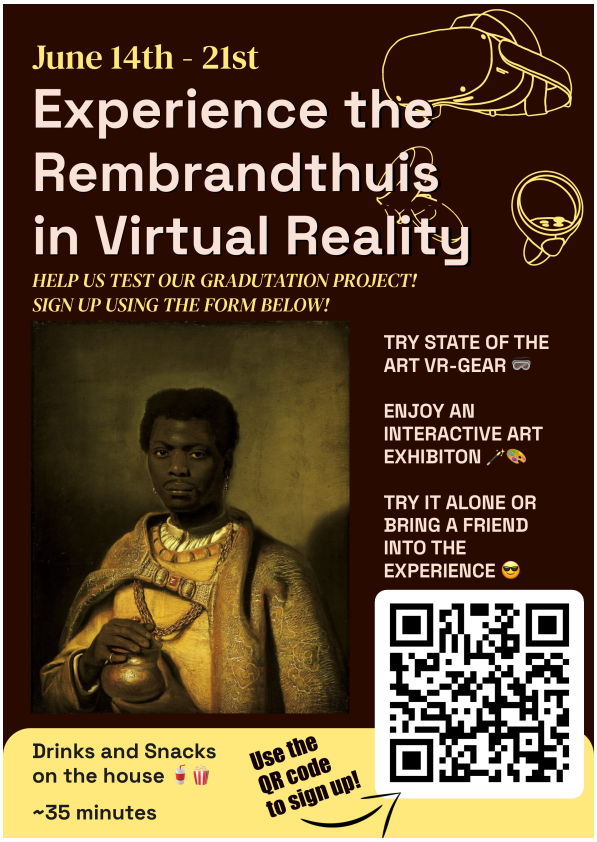

Figure 18: Recruiting Poster with QR-code

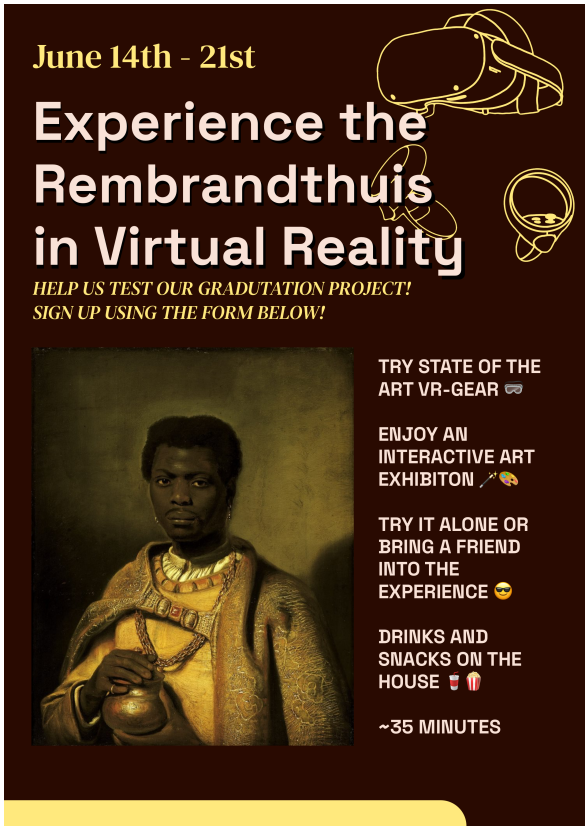

Figure 19: Recruiting Poster without QR-code

D.2 - Consent Form & Information Letter

Consent Form for a user study on the development of an art exhibition in social VR
YOU WILL BE GIVEN A COPY OF THIS INFORMED CONSENT FORM

Please tick the appropriate boxes	**Yes**	**No**
Taking part in the study		
I have read and understood the study information dated 10.05.2023, or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	□	□
I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	□	□
I understand that taking part in the study involves taking part in the user testing of a prototype for a virtual museum visit with multiple visitors. Additionally, I understand that taking part in the study involves taking part in a concluding questionnaire and interview with the researcher, which will be captured with audio recordings that will later be used to transcribe the interview to text and then be destroyed.	□	□
Risks associated with participating in the study		
I understand that taking part in the study involves the following risks: Motion sickness and similar effects on the participants physiological state caused by using Virtual Reality with a Head-Mounted-Display	□	□
Use of the information in the study		
I understand that information I provide will be used for the completion of a written bachelor thesis on the effects of Social Virtual Reality on the engagement of visitors of a virtual art exhibition.	□	□
I understand that personal information collected about me that can identify me, such as [e.g. my name or where I live], will not be shared beyond the study team.	□	□
Consent to be recorded		
I agree to be audio recorded.	□	□
Future use and reuse of the information by others		
I give permission for the data collected in questionnaires, surveys, and audio recordings that I provide to be archived in anonymised text files and audio transcripts so it can be used for future research and learning.	□	□

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Figure 20: Consent Form for Participants of the User Study

Information Letter
User Study on a virtual museum visit using Social Virtual Reality

Dear reader,

In this letter, you will find all information you need to know about the research you have agreed to participate in.
The session of this study will take place in the Citadel building in room T202 at the University of Twente (Drienerlolaan 5, 7522 NB Enschede).

Purpose of the research:
The purpose of this research is to evaluate a prototype of an interactive virtual museum exhibition. The exhibition is a virtual representation of the exhibition "HIER, Zwart in Rembrandts tijd" ("HERE, Black in Rembrandts Time"), which is a collection of paintings on display in the Rembrandthuis Museum in Amsterdam. The paintings show people of colour that lived freely in the Netherlands during the 17th century, the time of painter Rembrandt as well as the Dutch colonial period. The exhibition in its physical as well as its virtual version aims to educate about the history of people of colour living in the Netherlands and fight stereotypes.
This research is part of a bachelor's thesis for the study program Creative Technology at the University of Twente.

Structure of the session:
The session will begin with a short briefing to ensure you can give your informed consent to the procedures of the research. It will also be a moment for you to express any concerns or comments before starting the experiment. Furthermore, all necessary information needed for using the virtual reality devices will be given to you.
Afterwards, you will be required to take part in the main testing experiment of the virtual exhibition. For this, you will wear a head-mounted display, usually referred to as a "VR-Headset". Once the virtual reality environment is set up according to your height, you may begin exploring the virtual exhibition to your liking and try out the possible interactions within the virtual world. During this period you may be paired up with another participant to experience the VR exhibition together.
If you experience trouble with anything you may receive assistance, if you specifically ask for it.
After you choose to end your test visit at the virtual art exhibition, an interview about your experience will be conducted to evaluate the different aspects of the prototype. For better context evaluation, you will also be asked to answer a few questions on your typical attitude towards traditional museums, as well as your familiarity with different technologies. Additionally, you will be asked about your age and gender identity.
The session will end with a short debriefing in which you will have the opportunity to ask any remaining questions.
The total time estimated for the session is 30 minutes ± 10 minutes.

Risks:
Participating in this research's user testing does not involve dangerous procedures that can lead to bodily harm. However, using the virtual reality environment can cause motion sickness, disorientation, or similar effects.
The research procedure has been reviewed by the Ethics Committee of Information and Computer Science at the University of Twente and was considered safe.

Rewards & Benefits:

Your participation will be of great help in the development of a novel way to experience museum exhibitions that provide valuable education to the public.
Your participation will not be compensated with a monetary reward. Instead, snacks are provided to all participants.

Withdrawal of the study:
Your participation in this study is entirely voluntary. As a voluntary participant of this study, you may decide to withdraw from your participation at any time during the study as well as up to 24 hours after the end of the study. Withdrawing from the study entails that all data collected during your personal session may not be used in the research and will be destroyed.

Privacy matters:
For the evaluation of the research, collecting data during the study is necessary. Data will be collected in the form of screen recordings of the virtual environment, audio recordings taken during testing and the following interview. Additionally, your answers to surveys and notes by the researcher will be collected in text form. All audio recordings will be transcribed to text and then deleted.
All the data collected during the research will be handled confidentially and anonymised. Collected data will not be disclosed to third parties without your permission.

For any questions or concerns, please contact me, the researcher, via the following email address:
m.a.hauschild@student.utwente.nl

Yours sincerely,
Maximilian Hauschild

Supervisor: Dr. Shenghui Wang
Email: shenghui.wang@utwente.nl

Critical Observer: Dr. Ir. Robby van Delden
Email: r.w.vandelden@utwente.nl

University of Twente, 10.5.2023

Figure 21: Information Letter for Participants of the User Study

D.3 - Questionnaire & Interview Questions

Questionnaire Section 0:

1. Please indicate your age
2. Please indicate your biological sex

Questionnaire Section 1:

1. How much were you able to control events?
2. How responsive was the environment to actions that you initiated (or performed)?
3. How natural did your interactions with the environment seem?
4. How completely were all of your senses engaged?
5. How much did the visual aspects of the environment involve you?
6. How aware were you of your display and control devices?
7. How compelling was your sense of objects moving through space?
8. How inconsistent or disconnected was the information coming from your various senses?
9. How much did your experiences in the virtual environment seem consistent with your real-world experiences?
10. Were you able to anticipate what would happen next in response to the actions that you performed?
11. How well could you localise sounds?
12. How well could you actively survey or search the virtual environment using touch?
13. How compelling was your sense of moving around inside the virtual environment?
14. How closely were you able to examine objects?
15. How well could you examine objects from multiple viewpoints?
16. How well could you move or manipulate objects in the virtual environment?

Questionnaire Section 2:

1. To what extent did the game hold your attention?
2. To what extent did you feel you were focused on the game?
3. How much effort did you put into playing the game?
4. To what extent did you feel consciously aware of being in the real world while playing?
5. To what extent were you aware of yourself in your surroundings?
6. To what extent did you notice events taking place around you?
7. Did you feel the urge at any point to stop playing and see what was happening around you?
8. To what extent did you feel that you were interacting with the game environment?
9. To what extent did you feel as though you were separated from your real-world environment?
10. To what extent did you enjoy the graphics and the imagery?
11. When interrupted, were you disappointed that the game was over?
12. Would you like to play the game again?

Interview Questions

1. Which component of the interactive exhibition stood out to you the most?
2. How did your active participation in the quiz change your perception of the topic of the exhibition?
3. To what extent did the ability to grab and look at the objects affect your learning experience?
4. What did you perceive as the interaction that you engaged in the most besides moving around?
5. What effect did the exhibition have on your view of Dutch history in the 17th century?
6. What was your most significant learning moment?
7. How does your visit to the interactive exhibition in VR compare to how you personally visit art and history exhibitions?
8. How did the fact that you have an avatar change your experience of the virtual space?
9. How did wearing the VR headset (HMD) affect your experience?
10. To what extent did the software itself impact your experience?
11. Do you have any remarks or comments? (Asked last in any case)

Multiplayer questions:

1. How did the ability to see and communicate with another visitor change your experience?
2. What did you do in this setting that otherwise would not have been possible?
3. What effect did seeing the other person in the game world have?

D.4 - Notes

Observational notes

P 1, single:

Learning to move quickly; Finding an object after a short time of confusion (not reading the instruction); Needs adjustment for movement; Does look at paintings; not at text; Seemingly enjoys finding objects; Realises that she did not read the text below the paintings

P2, single:

Looking closely at paintings and text; Turning around instead of using the thumb-stick to move orientation; Taking a long time exploring while not engaging in the task; Understands interactivity after a long time (Researcher gave hints); Understands and reads quiz questions as well as answers; Has trouble understanding English words such as pompous and vessel; Seems interested in finding the correct answer to the quiz questions;

P3, multi:

Talk about questions and where to go with her partner; „Why do you always find the nice things?“; Talking about interesting/fun aspects of the answers

P4, multi:

Communication -> “ah what is it, a hat?”; An indication that Participant 1 found the object to the other participant; Checking in, “do you also think the right one is the correct answer?”; Waiting/indicating to wait, the participant was not done reading; Discussing the reasoning for the chosen answer.; “Why do you think it is correct?”

P5, multi:

Quickly understanding controls; No Talking between participants; No collaboration at first; Discussing how to answer the questions later; Interested in multiple texts; Interested in / reads answer-texts; Checking out the exhibition individually, sometimes meeting up to continue with the task; Seemingly not comfortable talking via Neos (?); Not sure what the answer is or what the object actually is; Expresses happiness about getting it right; Unhappy about the other person skipping over an answer; Stays in the exhibition after finishing the interaction part

P6, multi:

“We just need to walk around right? Checking in on what to do. I think there is something here. It is a bit blurry. What do you think the answer would be?”

First misunderstanding I think that they were supposed to work together.

Checking around, where are u?

Not sure what this is? Were confused about the tusk (really made them think)

“Oh yes, I know where that one is located”, showing the other participant the object. Discussing the different questions with argumentation as to why they think it fits with the objects.

Adjusting the lenses helped with seeing the text and surroundings more clearly.

P7, solo:

Reads instructions thoroughly; Appears happy about finding objects and grabbing; Thinks about which answer is correct; Not sure how to answer questions -> not enough knowledge given through the paintings (?)

P8, solo:

Forgot to press continue in the beginning; Mastered grabbing from a distance; Reads part of the explanations ; Focuses on completing the interactive part; Ends up looking more after finishing the interaction

P9, solo:

Reads text out loud, communicates with researcher; Issues with lag; Contemplates about answer options; Takes time to find and look at all painting

P10, multi:

Happy about movement;Thinks he needs to grab paintings; Trying to grab things from all paintings; Discusses info with the other person; Discussing historical details; Technical problems with the other person; (“Hunting trophy” seems ambiguous for non-native speakers); Looking at all paintings; „Seems like a trophy from an elephant“; Completes all tasks, other person does not really have the chance; Goes back to the painting to look at it more closely, trying to solve the quiz question; Skimming over answers; Immediately knows the third objects; This guy seems to be a noble person, realisation; „Yeah you were right“ - after clicking an incorrect answer; Enjoys jumping around, grabbing random things

P11, multi:

Checking where the other participant is.; Looking at the 3D object to inspect its possible materials; Reads the questions and text; Checking, “yes that should be the correct object”; (Hands are stuck don’t know why);

Discussing decisions, “what do you think it is? Who brings sand? Rum does not fit in the pot because it would spill."

P12, single:

Not reading any instructions ; Neos Freezing; Reads quiz questions; Clicks accidentally; Thinks out loud about possible answers; Moves through the exhibition quickly without looking too much; Comments on controls; Goes back to check out more paintings after completing all tasks

P13, single:

Reads instructions thoroughly; Reads intro text of the exhibition; Moves slowly; Clicks wrong answer on accident, Reads texts of different paintings; sFinds objects after looking at all paintings

P14, single:

Runs through the exhibition first; The controller battery ran out; Goes back to the instructions; Looks at paintings and descriptions more in detail; Controllers are not being tracked correctly ; The hat makes the program lag; Hands are not tracking; Accidental input on the first answer; Reads answers; Input not detected sometimes; Grabbing does not work correctly; Skipped the second answer , Grabs objects directly after grabbing with the laser; Goes back to read descriptions of the paintings to find out what the right answers are.

P15, single:

Reads descriptions and looks at most paintings; Finds the hat quickly, not lagging; Goes back to look at the description to answer the quiz question; Looks at more paintings; Avatar Arms freak out; Gets most answers correct

P16, single:

Hand glitches; Reads descriptions of the paintings very thoroughly; Actually looks at the second room; Hat freezes the game ; Reads all the texts; „It spins, nice“; Finds the second object very fast ; Argues for and against answer options ; Chooses the right ones based on his knowledg; „That’s interesting, it's the main export product of the Congo“; „Yes I got it, cool“; Goes back to learn about the story of Caspar; Argues against sand and liquor, laughs about sand as a gift; Reads all answers to get all answers correct

P17, multi:

“Pompous headwear right?”; “Controls are a bit hard. Oh, he has pompous headwear!”;

“What object do we need? I think it has sand, no I think it should be incense”; “Looks really cool”; Tactics of doing it more individually and seeing who was first

P18, multi:

Looks at paintings, not so much at the texts; Steals hat from the other person; Laughter; Not really paying attention to the contents; Looking closely at the details of the hat; Grabs tusk directly out of paintings; Lag; Makes multiple mis-inputs; Discusses with the other participant, and gets into a fight about who gets to do what first; Finally discussing answers and getting to the correct answer; Playing around with the hat; Very playful attitude towards the exhibition; Digital high five; Not paying attention to any additional artwork; Playing with objects

P19, single:

Gets familiar with controls first

Does not click continue right away

Reads texts of artworks first

Does not do the interaction at first

Goes back after being prompted to (time constraint)

Grabs hat directly from painting, walks back straight away without looking closer

Looks at the hat when on the pedestal

Finds the second object immediately

Does not narrate himself through the experience

Reads answer completely

Finds the last object immediately too

Goes back to see the final room after the last answer and interaction component s

P20, multi:

don’t really know what to grab or where to go; Don’t really know what to do, goes back to read the instruction ; Still, don’t know what they are looking for; “What did you find? Give it to me!”; Puts elephant tusk instead of the hat, gets error sound ; Other guy is mostly clipping through walls; Grabs incense vessel; Both find the hat; Brings back the hat; Skims over answers before the other guy comes back; There must be an explanation under the painting; Does the quiz alone; Does not wait for the other visitor; „Ah it's not this“, after putting the wrong object again ; Both enjoy gesturing; Skips answers, but do the second part of the quiz together

P21, multi:

Clipping through walls, not really knowing what to do; Finds hat!; Does not come back to do the quiz; Enjoys gesturing; Skips answers

Interview Notes:

1. Which component of the interactive exhibition stood out to you the most?

A: When you can take something out and take it a closer look. It's more interactive, which helps with thinking about the painting

A2: The quiz is interesting. I did not realise I had to do something, I did not read the instructions.

A3: Picking up the last object, because that is the only one I picked up myself

A4: the paintings, the grabbing of the objects, they looked really realistic

A5: Grabbing the objects out of the paintings, also the quest

A6: my hands, being able to grab stuff

A7: I really liked the fact that you could look at the painting really closely. In terms of interactions, the tasks make you take a look at every painting to find what you're looking for

A8: The fact that you could grab things from the paintings

A9: I liked that you could pull out items from behind paintings and bring them closer to observe, walking around was also fun

A10:playing together, interacting with each other giving feedback.

A11: the VR avatars were not working correctly (crossed arms) broke the immersion, otherwise the treasure hunt and the quiz to learn a little bit.

A12: Grabbing the objects, I wasn't expecting that.

A13: Picking up the objects, that was fun

A14: The pedestal. It had the best interaction. It would suck the objects in and they would turn, also it activated the quiz

A15: Grabbing things from the paintings

A16: the interaction with the hat. It was the first real interaction and made the first impression. I was really surprised when I was able to grab the hat

17: grabbing things out of paintings

A18: The fact that you could grab things, and even though that wasn't intended, it was kind of a race. It made me not really read through the text property.

P19: I liked picking up the artefacts

A20: the treasure hunt in a museum was really interesting

A21: the bigger paintings, the small ones seemed grainy. I liked the treasure hunt too, I would like to have gravity, also with the laser I could get the objects from anywhere and not have to go close, I would have preferred that

2. How did your participation in the quiz change your perception of the topic of the exhibition?

A: Didn't really read

A2: It made me want to know more

A4:it was interesting, you get more background info, otherwise, just look around.

A3: I was more engaged in reading since I needed to know what to do next. I thought more about the objects in the paintings

A5: made it feel more like a game than serious, but that also made it more fun to learn something

A6: more busy with finding the objects and answering the question than the exhibition itself

A7: I learned more about the way black people are perceived in art from the 17th century

A8: I felt like I rushed through the paintings to find the objects. I didn't really look at the text, I just thought about the task

A9: it was interesting because I could understand what the item and painting were about, cool fun facts because I didn't read the actual text next to the paintings

A10: it didn't really change. It was coherent

A11: It helps understand more, by answering the questions you get more info. For the tusk, it does not say anything about it in the painting, but you learn more during the game

A12: It gives you more of an insight into the topic. After the quiz, you read more than you would with the text under the paintings, especially because you're looking for the things first

A13: it made me think more. Like, did I read about it or do I have to guess?

A14: I had to pay more attention, but I'm usually not a museum type (a person that goes to museums), so I tend to skip the descriptions

A15: I thought about it more than I would've otherwise, but my opinion didn't really change, because I didn't really have one. I still don't, just a little more

A16: it made it more playful in a way, this way of giving information might be more suitable for educating younger people

17: did not really focus on the qui part more of the game and how it worked. Did not look that much at the quiz

A18: it made me more involved and interested, it was nice that you could always look at the paintings since it's digital. Not sure if the questions had much to do with the paintings themselves. We maybe should've taken our time to read through everything.

A19: it's like one more tool to teach people, so I think I learned more through that. It feels more real, when there e.g. a hat floating around and you can inspect it from all sides, it's less arbitrary

A20: I was always pro-VR, I didn't know that it could work together like that with a museum.

A21: I don't know, I would've preferred a more colourful topic, more like general history. Maybe the room could've been more bright.

3. To what extent did the ability to grab and look at the objects affect your learning experience?

A.: In the beginning I wasn't used to the controls, learning curve. Learned how to use the controls

A: It does really affect it and I wanted to get the quiz questions correct

A4: It made you more connected to the object you're learning about.

A4: made it more engaging so that I could look at it from more sides, and understand better what the image is showing

A5: It was interesting and it made it more clear what it meant in the painting, but for the first one I had no clue what was what

A6: A lot, to a great extent. Both blocked the learning a bit because you're more busy with finding and completing the tasks instead of reading. At the same time, the interaction did cause you to go to the artefacts.

A7: The interaction made it more immersive, you had to pick it up and look at the details of the objects

A8: Maybe the fact that when you place them down you're asked a question about it

A9: was interesting to look at them up close, I struggled walking with them. Once you take them out you could really understand what they mean t

A10: program difficulties

A11: it made it more interactive since you could go and search, but it was also a bit unnatural, why would you grab stuff?

A12: Sometimes I got stuck, so I got a little scared to go close. They spun around on the pedestal, which was cool because you could see more of them. The hat had a lot of detail, which was nice, the other ones did not so much, so I didn't look at them for long

A13: I would grab them and look at them for a second, but not really that much, I didn't inspect them

A14: Grabbing and looking didn't really work, because the controllers were janky, so I was mainly trying to bring the objects back. I looked at them when it was on the pedestal. Maybe I could have done more with them, like bend under it or something.

A15: You focus on it a bit more if you grab it, but I didn't look at it too closely. But I was looking at the paintings closely to find what I was looking for, so I was more involved.

A16: I don't think that the grabbing of things really enhanced the learning but the quiz that was connected did enhance it, in the way that you were given three options with different difficulties. I found 2 to be very realistic and one always definitely wrong.

17: really liked that I could inspect it before answering, the feather is a nice model

A18: it makes you pay more attention to the details of the paintings, so you would observe them more closely. That might help with keeping them in your memory

A19: Positive, I didn't quite realise that was a thing until I went back to the first room, after looking at most of the exhibition. It would've also made me more motivated to look at the art

A20: a lot, because I could really inspect the objects, I could look at the hat from all angles

A21: it was nice to turn them with the joystick, sometimes things were far away and I couldn't figure out how to get them closer

4. What did you perceive as the interaction that you engaged in the most besides moving around?

A2: Grabbing and touching It made me more active while looking at the paintings

A3: talking to the other person, we talked through it the whole time (what to do next etc)

A4: the grabbing, choosing the right answers

A5: Searching for the objects

A6: grabbing stuff, interacting with it

A7: Grabbing the objects

A8: Picking up the objects

A9: Picking up the objects

A2: Having to grab objects

A10: grabbing was cool, enjoyed the quiz.

A11: Jumping, because it was fun! When you learn that, it becomes fun! And of course, grabbing stuff

A12: The third task was to grab the incense jar and I tried to grab that from the painting in the main room, but tried with the version in the hall. The quiz was also kinda fun

A13: Grabbing stuff

A14: Trying to grab the objects

A15: answering the quiz question

A16: Reading all the information about the paintings.

A17: interacting with the other player, a bit of competition in finding objects.

A18: Trying out different stuff, even though it was not the objective. Try to see what you can look at, what you can interact with and so on

A19: The interaction of picking up objects from a painting. It was more smooth than I expected and it's more interactive.

A20: the interaction with Mike was quite important, but having gravity would make it more realistic.

A21: it was nice to interact with the other person, I felt like I could move Marios around, and I could also grab something from his hands

5. What effect did the exhibition have on your view of Dutch history in the 17th century?

A: Just got some info about the object. I was more focused on walking and interaction

A2: It gave me more knowledge through the interactions.

A3:I think I didn't get a lot of new knowledge, since I didn't walk through the whole exhibition to look at all the paintings, but it made me more curious

A4: I didn't really learn it in school so didn't really know anything, so don't know if it changed without prior knowledge.

A5: I'm not really interested in history, but it showed me more that I didn't know yet

A6: I didn't know that there were many black people in the 17th century in the Netherlands, besides that, not a lot.

A7: I changed my perspective on the way black people are perceived in art. That they were not only perceived as slaves but also as noble in a way, with fancy clothing and trophy. It is like a realisation that black people weren't only slaves in those days, but there's more to it

A8: I already knew about this exhibition and Dutch history in the 17th century, I took art history in high school and love learning about the Dutch golden age.

A9: I don't think I would've gone to the actual museum, because it didn't seem appealing to me, but it was interesting in VR. Touching stuff is cool

A10: don't really have a view, so nothing really changed

A11: I already knew a little bit about the exhibition and I learned some interesting stuff about it.

A12: It's kinda interesting that the guy with the hat was viewed as a noble person or someone with power, but also did the slave trade and such.

A13: Honestly, not very much because I was more focused on the game. I think I still learned more than if I had just gone through the normal exhibition

A14: I'm not a fan of museums in general, but I would rather try the VR museum than a normal museum. It's new and interesting to try out. I think I learned that they colonised a lot and there were a lot of poor people, mainly black people. But in the exhibition, they all had gold stuff, so they weren't all poor I guess. I didn't really read the labels.

A15: I'm slightly more interested in the topic because I wasn't interested in it at all before.

A16: I learned some new things. If I recall correctly, it started out pretty positive, but later they moved the people more to the background of the painting. So it started positive and turned negative.

A17: showed some inside information about the history of black people in the Netherlands

A18: It was more engaging. It felt more dynamic. You were scanning for certain paintings. It didn't really know too much about the history of the time except for colonialism. It was interesting to see this representation of the time in art, it made me look at the topic differently. I wanted to know more about how the people lived in those times.

A19: I donÄt think it changed much, I am aware of the diverse but also colonial past of the Dutch, but I learned about this culture specifically,

A20: mostly learning about exotic products from foreign continents. It's very different from Greek history

A21: I'm a bit confused about the historical aspect. I've been to some Dutch modern art and history museums, but I didn't understand a lot there either.

6. What was your most significant learning moment?

A: Understanding the controls

A2: Having to answer the quiz and wanting to know the correct answer

A3: Figuring out together what the materials and objects mean.

A4: that the accessories looked interesting, the details on the clothing

A5: It was more active learning to figure out the right answers to the questions. Also, the answers after, except for the time [other person] skipped the answer

A6: second question, confusion o nether meaning of the object.

A7: Being able to look very closely at the paintings, where you can really look at the details

A8: That black people are also important in Dutch history and not just white people, which was never touched upon in my Dutch courses.

A9: I liked that I was able to guess that it was an ostrich feather. I learned most about the beaver hat.

A10: walking and jumping

A11: When we got a correct or incorrect answer we got more information. With a game, you get more information than by looking at a painting. I also didn't know that incense had the meaning of deity

A12: I was intrigued by the fact that black aristocrats were also trading with the Dutch

A13: Learning about the story of King Caspar was interesting in the context of Christmas traditions and such.

A14: During one question, the last one, I had to look at both of the pictures in two places, that was a learning moment.

A15: Moving around, and seeing what VR and the controls are like are the biggest things ill remember from this. It was my first time in VR.

A16: I don't remember the name of the person, but the one guy with the hat (Dom Miguel) seemed really wealthy. Also, he was trading with other countries and seemed a bit of a controversial person

A17: walking, I was more focused on the technical side

A18: I'm not sure. It was a bit short since we didn't take a lot of time to look at it. I liked the quiz and the info that popped up after the quiz, that gave you a better perspective.

A19: I wasn't aware that Rembrandt painted so many black people, that was the main thing I learned. That was not very common back in the day

A20: Figuring out the difference between the laser and the grab interaction, it was also nice that it was very responsive

A21: When I realised how to really grab stuff

7. How does your visit to the interactive exhibition in VR compare to how you personally visit art and history exhibitions?

A: Because you can grab stuff and move it it gives you a 3D experience and makes you more engaged with the painting and the person in the painting

A2: the real thing is different, in VR I could engage more in the immersive, fun activities.I think you learn more

A3: I wasn't as concerned about other visitors, I didn't have to be quiet, i could move around and interact with the exhibition how I wanted. Normally you are not allowed to touch anything, here I could grab something. In a normal museum, i could look at the images for longer since the VR headset makes me move through it quicker

A4: very different from how I normally look at art. Do like museums and look at art to see what I like about it. Don't often read the text, more how I experience it. Here it's in the experience, to learn more playfully.

A5: when I go to ordinary ones, I'm more with other people and do it as a group, now we were more apart and it was more of going back and forth

A6: more interactive but more distracting from the art itself.

A7: The gamification made it so that you really have to look at every painting, whereas in a museum you would skip the less glamorous ones

A8: It was fun that you could grab things, that's not possible in real life. It also points out important things in the paintings. You get specific facts about those things. In a normal museum, you have to hope that they write something interesting.

A9: I don't have to be serious in VR, I could fool around and walk around and sort of guess what everything means in the quiz and get the info later, instead of reading a lot of boring text. I'd like to go to more VR museums

A10: I can spend way more time in person than in VR. Would look maybe closer, but I have limited ability in VR.

A11: the good point about VR is that you get more information about the painting than in a normal thing. Real life is still better of course

A12: this is a bit more interactive for sure, so that was fun. However, I think you could do some of that in real life too

A13: it was more fun because I'm not that big of a fan of just history, this felt more like history-based art. This was definitely way more fun than in a normal history-based exhibition

A14: you can move faster in VR, so you can quickly go back to something else. There are no other people, so you can walk straight without dodging people. The paintings are never crowded, so it's easy to see all of them.

A15: If I were to go there in person, id go with my parent and go slow, so I wouldn't read the signs, but this way I was more inclined to read

A16: usually I don't visit exhibitions all that often, but I think this was a bit more interesting because of the interactiveness. Also, I think this is a bit more accessible because you could upload this and people could visit from their own house.

A17: could be a nice addition but would rather go to a real museum. Could be fun as an addition to a real museum

A18: you feel more free, you can move around easily, don't have to be quiet. Since it's with a friend it's really fun and you can do whatever you want. I guess it's also more accessible.

A19: There are some positives and some negatives. Moving around does not feel as natural. Walking at your own pace feels more normal. In an actual museum, you can inspect art more in detail and see the textures, here you cannot get that value from it. On the other hand here you can touch the painting and actually take objects from it.

A20: I like travelling, but going to a museum is either a chore or the main purpose of the visit. This is a bit more casual. Nice to broaden the horizon

A21: it would continue doing this right now, whereas, in a real museum, I would probably be done. Its also very nice to be able to do this from home on a rainy day or when you can't travel

8. How did the fact that you have an avatar change your experience of the virtual space?

A: I didn't notice, I didn't see it.

A2: I didn't see it.

A3: Having arms made me feel more like I was actually there. It didn't feel like that was me, however, more like I was playing something.

A4: didn't notice my own avatar. But seeing someone else made it more realistic

A5: Being a person kind of thing was nice, but I couldn't see much of the avatar itself, so it didn't really make a difference

A6: I only saw my hands but did see the other person, kinda felt like you actually were interacting with someone.

A7: not at all. If there was another person, it would make it more immersive

A8: Having hands was nice, other than that it didn't make a difference.

A9: It was nice because you feel more like you're inside the world, it was nice to see my hands, which would maybe also help with motion sickness

A10: makes more sense, moving around is more intuitive.

A11: controls weren't perfect, so that was a bit weird, except seeing her avatar move weirdly, it was quite

A12: not that much. It looks like hands, but at the same time when holding something it still floats in front of you.

A13: I found it very funny that I had manly hands, but I didn't really see the rest of my avatar, so I can't really tell

A14: I didn't really look at it, but I saw that I had legs and arms. It felt more human. A little more like your part of the virtual world. I felt less distouched from the world

A15: not much, you don't really see the guy.

A16: It's a first-person game, so you don't see the avatar much, except when the hands glitch. It does not have much of an influence, it could've just been a camera without a person attached to it

A17: I could not see myself but was fun to interact with the other player.

A18: I couldn't see myself, but it was nice to see your friend's avatar. I could see where he would go, which made it more immersive and interactive.

A19: Not much, I only saw the hands sometimes. In real life, I felt like I was reaching further than the avatar was in the VR.

A20: My own avatar wasn't very accurate, I didn't mind at the moment, but if I did this again, I would build my own accurate avatar. Mikes was pretty accurate, taller than me and had black hair

A21: I could only really see my hands, but customisation would be nice.

9. How did wearing the VR headset (HMD) affect your experience?

A: It was ok, in the beginning, there was a lot of open peripheral vision on the side. Towards the end, I didn't notice anymore, quest pro

A3: I don't really like wearing VR headsets, I find them uncomfortable. I would prefer to not have them on. It was a hindrance since I wanted to stay there for longer. It was weird that I could see things outside the headset (Quest Pro)

A4: this headset is better than Oculus and more comfortable. Didn't really notice it. Was a bit blurry. After a while you ignore it. Especially if you wear glasses you also ignore that.

A: Doesn't have an effect except for immersion

A5: It was more immersive than on a screen.

A6: kinda unsharp even with glasses it kinda looked like you had a shadow.

A7: it allows you to look around, the immersion breaks a little because you have a peripheral view (Quest Pro).

A8: It made it more immersive. It's also a geeky moment the first time you put it on.

A9: this headset (quest pro) was really easy to use. I usually get motion sick, but not with this one, since I could glimpse outside

A10: it's very hot and a bit heavy, maybe have bigger physical space.

A11: A lot, the fact that you see on the side, removes immersion. I would check what was happening on the side. Quest pro

A12: in my opinion, VR makes it harder to move through spaces a lot of the time. While it brings you to another space, traversal and task completion are more difficult, I struggled with navigation

A13: in the beginning, you had to get used to it and then it's fine. With this headset (quest pro) I could see a lot outside on the sides, but later I focused more on the VR and didn't notice it anymore

A14: It was sometimes hard to focus on text, so i had to keep adjusting the headset, also because of my glasses. The controllers were not working correctly for me.

A15: I didn't really notice that I was wearing the headset. It was a bit warm. My eyes couldn't always focus correctly, but it didn't give me a headache, it was slightly distracting though.

A16: It was a bit difficult to see the paintings from very close, it was better to view it from a little further away. I couldn't get as close as I wanted to in the museum

A17: not really, I know how VR works you have a certain type of expectation.

A18: I ended up forgetting about it a little bit, but I got reminded when snap-turning, which made me a bit dizzy and took me out a bit. I didn't feel it too much, wasn't distracting and I was immersed.

A19: I'm personally not that big of a fan of these headsets because I get dizzy sometimes, but over this short period of time it was quite ok.

A21: it's pretty light. Lighter than the PSVR, which is heavy. It's nice to have two controllers that have hands

A20: it was light enough to move your hand a lot. The grabbing was very natural too

10. To what extent did the software itself impact your experience?

A: I noticed that when I move too fast, it did not respond quickly.

Very different from normal experience, since you feel like you're there

A2: Made me dizzy when moving fast.

A3: The reaction time was good, it did not lag. The controls were intuitive if you used VR before. Moving around is a bit harder because it is unpredictable.

A4: stopped working, but that happens often with VR. Rendered very well. Blurriness is more the headset than the software.

A5: it froze once. The graphics are quite good already, but you can clearly see that it is a virtual environment. Some controls were unexpected

A6: was very responsive, weird that some objects such as the lamps weren't actually there.

A7: It was simple to move around, exploring was easy. It froze for a second, which broke the immersion

A8: It ran smoothly, didn't have many problems with it, which was good. Otherwise, it would've been frustrating

A9: At the beginning it lagged, but then I could spend time looking around once it was working

A10: lack of hand control, glitching, appearing and disappearing was unpleasant, space was great

A11: It did not feel like real life, but entertaining.

A12: I got stuck in the hat, which was strange. Other than that it seemed to work fine. Moving the camera in increments was strange, I lost track of the direction

A13: Sometimes it would lag a little bit. I found it weird that when I had the object in my hand, I didn't feel like I was in control of my movement as much.

A14: I had problems with the controllers, so I felt blocked. I had to try to fix it and lost touch with my surroundings. Sometimes it lagged and I could see the things outside the main window. It was not very smooth.

A15: The jittering hands were definitely distracting and were causing problems with the controls. Also, i was sometimes walking backwards when I wanted to go forward

A16: the hand tracking degraded the experience for a bit. But that's more of an issue with the headset itself.

A17: the walking was very difficult, when moving very fast it was a bit glitchy.

A18: The paintings were beautiful and the readability was fine. It was a bit greyish, but I guess that's VR. The aesthetics could be improved a bit to make it more. The interactivity was very dependent on the questions and not quite fine.

A19: I think I'd rather have the possibility to gradually turn instead of snap turning, it's way different from reality and disturbs the immersion. But apart from that neutral.

A20: I would have preferred smooth camera turning

A21: Everything was smooth but very sensitive, but a little too much. Also, walking is nice with a stick, but teleporting would maybe be better. I liked that you could look somewhere and then walk there

Multiplayer questions:

1. How did the ability to see and communicate with another visitor change your experience?

A3: Made it more fun and engaging. For the quiz, it felt like we worked together. However, she (the other person) was mostly quicker and picked up the objects before I had the chance.

A4: made it more fun, you talk more, makes you more immersed. Otherwise, you would just select one.

A5: I think it was really nice. You could ask each other for help with the questions. Sometimes I was looking for him, but couldn't find him due to the controls

A6: made it more engaging and fun. Made the experience more relevant.

A10: very nice do it with someone you know, social experience,

A11: I think that was nice.

A17: having a little battle was very fun, interacting with each other.

A20: it was nice to talk to one other visitor, but I would not have liked it if there were more people there

A21: for now it would be nicer to have a visual representation of someone speaking, to see where it is really coming from

2. What did you do in this setting that otherwise would not have been possible?

A3: Figuring out together how to solve the quiz.

A4: more commenting, saying what I was thinking, discussing.

A5: Ask for help, discuss, and try fun things with the VR controls, like climbing the walls. It was also more comfortable to not be alone in an unknown environment

A6: grabbing stuff, don't know.

A10; grabbing objects from the paintings, looking at them in 3D

A11: it made it more immersive because you could really discuss answers. Answering the questions was more social, because of discussing

A17: putting my hands through paintings, grabbing 3D objects. Walking up and down often it's to crowded.

A18: that was quite fun, even though it was surprising when he would pop up next to me and i didn't see him walk up. We were very playful with it and it was fun to see what he was doing.

A20: Having fun together, exploring the museum

A21: Guessing the answers together was nice

3. What effect did seeing the other person's avatar in the game world have?

A3: Felt more like they were actually also there. A floating headset would've made it more disconnected. Even though it did not look like [participant 4] it made it more realistic.

A4: made it a more realistic, very realistic avatar. Made you feel like you were in a realistic space.

A5: At the start it was weird, I noticed it really. Later it was easier to use body language as well

A6: felt like you were interacting with an actual person.

A10:helps apprehend the space, it feels less lonely.

A11: Considering how it was behaving, it removed the immersion, but it was still nice to see another person,

A17: made it more interactive, I had a feeling of being together in the room

A18: It made me feel like I was in the space with an actual person, but the fact that i could not interact with him in the virtual space took away the immersion a bit. The height difference was also fun.

A20: It would be very easy to go to multiple museums

A21: It requires less movement and planning on where to go, it's just a call and you can go to the museum. I can also quickly go through it and go back whenever I want

11.Remarks?

A: It's a good thing for schools, I like the educational thought behind it.

A: I would like more than three questions. The grabbing is really interesting.

A3: I don't think so.

A4: not really, the objects were nice, textures looked great.

A5: not really, it was fun.

A6: it was fun, more than I expected it to be.

A7: I would switch the trigger function with the grab function and I would add gravity to the objects.

A8: No.

A9: Not that I could think of. It was really fun!

A10; no remarks, it was a great experience

A11: use another VR headset (not quest pro) and see about avatar movement. Also make it longer. Even with the issues, it would have been fun to continue. We only did 3 paintings in one area.

A12: No, I think that was it.

A13: No, I think it was really fun. I can see this being used either at a museum or for virtual tours during lockdowns or for people that can't go to a museum.

A14: Maybe make it slightly more realistic. The paintings were on the same layer as the wall, bringing them a little forward to give them a little more depth and realism.

A15: No.

A16: no.

A17: not really, control was. Ice and easy, a bit difficult with walking. Enjoyed it!

A18: I don't think so.

A19: no, I don't think so.

A20: add gravity and some more physics constraints

A21: add gravity

D.5 - Statistical Results

ID	Gender	Age	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	Group
1	female	26-29	5	5	4	5	4	3	4	3	3	4	1	5	4	5	5	4	5	5	4	2	2	4	5	5	4	5	4	5	single
3	female	22-25	4	4	4	4	5	2	4	4	2	4	4	4	4	4	5	5	5	5	5	2	2	2	3	5	4	5	5	4	multi
4	female	22-25	4	5	5	4	5	4	4	5	4	4	5	2	4	5	5	4	5	5	4	4	3	2	4	4	5	5	5	5	multi
5	female	18-21	4	5	4	5	4	1	5	3	3	4	4	4	4	5	4	3	5	4	4	3	2	2	4	4	4	5	3	4	multi
6	male	18-21	5	5	3	4	5	1	5	5	3	4	2	4	4	4	4	5	5	5	4	4	5	2	5	5	4	4	4	5	multi
7	male	18-21	4	5	2	3	5	2	4	5	2	5	1	4	4	5	5	4	4	4	1	1	2	2	4	5	2	5	4	4	single
8	female	22-25	4	5	3	2	3	2	4	4	3	5	1	2	4	4	3	4	3	3	3	4	3	4	4	4	4	4	2	4	single
9	female	18-21	4	4	4	4	4	2	4	3	4	4	2	4	4	5	5	5	5	5	3	2	2	3	5	4	4	5	5	5	single
10	female	30-33	3	2	4	2	5	2	3	4	4	4	3	1	4	3	4	3	5	5	4	2	2	2	4	4	4	5	3	4	multi
11	male	26-29	4	4	2	4	4	1	3	4	2	5	3	2	4	5	5	4	4	4	3	1	1	1	3	5	2	5	4	4	multi
12	male	22-25	4	5	4	4	4	2	4	5	4	4	1	4	4	5	5	5	5	4	4	3	2	4	5	5	4	4	3	3	single
13	female	18-21	4	4	3	3	4	2	4	3	2	4	1	3	3	4	5	4	5	4	5	3	2	4	4	4	3	5	4	4	single
14	male	18-21	2	4	4	3	4	2	4	2	3	3	1	2	3	4	3	4	4	5	5	3	4	3	2	5	5	4	4	4	single
15	male	18-21	2	5	4	3	4	5	4	5	3	4	1	2	4	4	5	3	5	5	5	4	3	3	5	4	3	5	3	2	single
16	male	18-21	4	4	5	3	5	1	4	5	5	3	1	4	5	3	4	4	5	5	5	2	1	1	4	5	4	5	4	5	single
17	female	18-21	3	4	4	4	4	4	4	5	2	5	3	4	2	5	4	4	5	5	4	4	2	2	4	5	4	4	4	5	multi
18	male	18-21	2	5	4	4	4	3	5	3	4	5	2	4	2	5	4	4	5	5	4	4	5	3	4	4	4	5	4	5	multi
19	male	22-25	4	4	4	4	3	1	4	3	2	5	2	4	3	4	4	5	4	5	4	3	2	4	4	4	4	3	2	3	single
20	male	18-21	5	5	4	5	5	1	4	4	5	5	5	5	5	5	5	5	5	5	5	1	1	1	4	5	5	5	5	5	multi
21	male	18-21	3	5	2	4	5	3	5	4	3	4	2	4	4	4	5	4	5	4	4	2	2	2	2	4	4	3	5	5	multi
																						inverse	inverse	inverse	inverse						

Table 4: Coded Results of Both Sections of the Questionnaire

Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.664	.685	16

Summary Item Statistics

	Mean	Minimum	Maximum	Range	Maximum / Minimum	Variance	N of Items
Item Means	3.731	2.200	4.450	2.250	2.023	.488	16
Item Variances	.811	.305	1.882	1.576	6.164	.174	16

Item Statistics

	Mean	Std. Deviation	N
S1Q1	3.70	.923	20
S1Q2	4.45	.759	20
S1Q3	3.65	.875	20
S1Q4	3.70	.865	20
S1Q5	4.30	.657	20
S1Q6	2.20	1.152	20
S1Q7	4.10	.553	20
S1Q8	3.95	.945	20
S1Q9	3.15	.988	20
S1Q10	4.25	.639	20
S1Q11	2.25	1.372	20
S1Q12	3.40	1.142	20
S1Q13	3.75	.786	20
S1Q14	4.40	.681	20
S1Q15	4.45	.686	20
S1Q16	4.00	.973	20

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
S1Q1	56.00	29.895	.354	.733	.637
S1Q2	55.25	30.197	.426	.905	.632
S1Q3	56.05	32.576	.099	.881	.670
S1Q4	56.00	28.000	.610	.934	.604
S1Q5	55.40	31.305	.352	.886	.642
S1Q6	57.50	34.895	-.139	.848	.714
S1Q7	55.60	32.568	.230	.883	.655
S1Q8	55.75	30.513	.280	.724	.647
S1Q9	56.55	30.682	.244	.787	.653
S1Q10	55.45	33.418	.068	.909	.669
S1Q11	57.45	26.892	.390	.939	.630
S1Q12	56.30	27.589	.453	.920	.618
S1Q13	55.95	31.524	.247	.914	.652
S1Q14	55.30	30.642	.428	.828	.634
S1Q15	55.25	30.408	.455	.776	.631
S1Q16	55.70	32.432	.085	.657	.674

Table 5: Questionnaire Section 1, Reliability Analysis Across Both Groups

Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.698	.710	16

Summary Item Statistics

	Mean	Minimum	Maximum	Range	Maximum / Minimum	Variance	N of Items
Item Means	3.869	2.200	4.600	2.400	2.091	.402	16

Item Statistics

	Mean	Std. Deviation	N
S1Q1	3.70	.949	10
S1Q2	4.40	.966	10
S1Q3	3.60	.966	10
S1Q4	4.00	.816	10
S1Q5	4.60	.516	10
S1Q6	2.20	1.229	10
S1Q7	4.20	.789	10
S1Q8	4.10	.738	10
S1Q9	3.20	1.033	10
S1Q10	4.40	.516	10
S1Q11	3.30	1.160	10
S1Q12	3.40	1.265	10
S1Q13	3.70	.949	10
S1Q14	4.50	.707	10
S1Q15	4.50	.527	10
S1Q16	4.10	.738	10

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
S1Q1	58.20	31.733	.428	.	.667
S1Q2	57.50	29.611	.634	.	.639
S1Q3	58.30	33.789	.222	.	.693
S1Q4	57.90	30.544	.665	.	.643
S1Q5	57.30	35.567	.224	.	.692
S1Q6	59.70	38.011	-.152	.	.751
S1Q7	57.70	34.456	.230	.	.690
S1Q8	57.80	35.733	.106	.	.702
S1Q9	58.70	33.344	.235	.	.692
S1Q10	57.50	36.944	.000	.	.706
S1Q11	58.60	29.822	.477	.	.657
S1Q12	58.50	29.611	.436	.	.663
S1Q13	58.20	34.400	.172	.	.698
S1Q14	57.40	33.156	.437	.	.671
S1Q15	57.40	34.711	.358	.	.683
S1Q16	57.80	32.400	.508	.	.664

Table 6: Questionnaire Section 1, Reliability Analysis for Multi-User Group

Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.570	.611	15

Summary Item Statistics

	Mean	Minimum	Maximum	Range	Maximum / Minimum	Variance	N of Items
Item Means	3.567	1.200	4.500	3.300	3.750	.755	15

Item Statistics

	Mean	Std. Deviation	N
S1Q1	3.70	.949	10
S1Q2	4.50	.527	10
S1Q3	3.70	.823	10
S1Q4	3.40	.843	10
S1Q5	4.00	.667	10
S1Q6	2.20	1.135	10
S1Q8	3.80	1.135	10
S1Q9	3.10	.994	10
S1Q10	4.10	.738	10
S1Q11	1.20	.422	10
S1Q12	3.40	1.075	10
S1Q13	3.80	.632	10
S1Q14	4.30	.675	10
S1Q15	4.40	.843	10
S1Q16	3.90	1.197	10

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
S1Q1	49.80	20.622	.346	.	.526
S1Q2	49.00	22.889	.264	.	.551
S1Q3	49.80	23.733	.011	.	.588
S1Q4	50.10	20.544	.424	.	.514
S1Q5	49.50	22.500	.246	.	.550
S1Q6	51.30	24.900	-.149	.	.637
S1Q8	49.70	19.344	.387	.	.511
S1Q9	50.40	21.156	.258	.	.544
S1Q10	49.40	24.267	-.043	.	.593
S1Q11	52.30	24.011	.075	.	.571
S1Q12	50.10	17.878	.601	.	.456
S1Q13	49.70	20.900	.553	.	.507
S1Q14	49.20	21.733	.367	.	.532
S1Q15	49.10	19.211	.619	.	.475
S1Q16	49.60	26.267	-.261	.	.666

Table 7: Questionnaire Section 1, Reliability Analysis for Single-user Group

Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.526	.558	12

Summary Item Statistics

	Mean	Minimum	Maximum	Range	Maximum / Minimum	Variance	N of Items
Item Means	3.825	2.400	4.700	2.300	1.958	.682	12
Item Variances	.749	.263	1.305	1.042	4.960	.120	12

Item Statistics

	Mean	Std. Deviation	N
S2Q1	4.70	.571	20
S2Q2	4.60	.598	20
S2Q3	4.00	.973	20
S2Q4	2.70	1.081	20
S2Q5	2.40	1.142	20
S2Q6	2.55	1.050	20
S2Q7	3.95	.887	20
S2Q8	4.50	.513	20
S2Q9	3.85	.813	20
S2Q10	4.55	.686	20
S2Q11	3.85	.933	20
S2Q12	4.25	.851	20

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
S2Q1	41.20	14.905	.482	.722	.461
S2Q2	41.30	14.642	.515	.538	.452
S2Q3	41.90	13.989	.333	.708	.468
S2Q4	43.20	13.642	.319	.745	.470
S2Q5	43.50	13.316	.328	.642	.466
S2Q6	43.35	16.976	-.083	.530	.589
S2Q7	41.95	15.524	.150	.699	.519
S2Q8	41.40	17.621	-.122	.351	.556
S2Q9	42.05	13.839	.473	.602	.438
S2Q10	41.35	16.871	.003	.473	.545
S2Q11	42.05	15.734	.102	.741	.533
S2Q12	41.65	15.503	.169	.617	.514

Table 8: Questionnaire Section 2, Reliability Analysis Across Groups

Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.729	.760	12

Summary Item Statistics

	Mean	Minimum	Maximum	Range	Maximum / Minimum	Variance	N of Items
Item Means	3.867	1.900	4.900	3.000	2.579	.959	12

Item Statistics

	Mean	Std. Deviation	N
S2Q1	4.90	.316	10
S2Q2	4.70	.483	10
S2Q3	4.10	.568	10
S2Q4	2.70	1.252	10
S2Q5	2.50	1.434	10
S2Q6	1.90	.568	10
S2Q7	3.70	.823	10
S2Q8	4.50	.527	10
S2Q9	4.00	.816	10
S2Q10	4.60	.699	10
S2Q11	4.20	.789	10
S2Q12	4.60	.516	10

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
S2Q1	41.50	20.944	.653	.	.706
S2Q2	41.70	19.567	.733	.	.686
S2Q3	42.30	20.900	.330	.	.717
S2Q4	43.70	15.344	.614	.	.667
S2Q5	43.90	14.544	.579	.	.681
S2Q6	44.50	20.056	.503	.	.701
S2Q7	42.70	18.456	.537	.	.687
S2Q8	41.90	23.433	-.152	.	.756
S2Q9	42.40	18.267	.573	.	.682
S2Q10	41.80	23.067	-.093	.	.761
S2Q11	42.20	22.178	.018	.	.754
S2Q12	41.80	20.178	.536	.	.700

Table 9: Questionnaire Section 2, Reliability analysis for Multi-user Group

Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.300	.309	12

Summary Item Statistics

	Mean	Minimum	Maximum	Range	Maximum / Minimum	Variance	N of Items
Item Means	3.783	2.300	4.500	2.200	1.957	.551	12

Item Statistics

	Mean	Std. Deviation	N
S2Q1	4.50	.707	10
S2Q2	4.50	.707	10
S2Q3	3.90	1.287	10
S2Q4	2.70	.949	10
S2Q5	2.30	.823	10
S2Q6	3.20	1.033	10
S2Q7	4.20	.919	10
S2Q8	4.50	.527	10
S2Q9	3.70	.823	10
S2Q10	4.50	.707	10
S2Q11	3.50	.972	10
S2Q12	3.90	.994	10

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
S2Q1	40.90	10.322	.514	.	.137
S2Q2	40.90	10.989	.356	.	.196
S2Q3	41.50	8.278	.435	.	.053
S2Q4	42.70	12.900	-.095	.	.364
S2Q5	43.10	13.211	-.123	.	.363
S2Q6	42.20	12.844	-.102	.	.375
S2Q7	41.20	13.067	-.114	.	.369
S2Q8	40.90	13.211	-.087	.	.329
S2Q9	41.70	10.678	.335	.	.188
S2Q10	40.90	12.100	.113	.	.279
S2Q11	41.90	10.989	.190	.	.240
S2Q12	41.50	12.500	-.047	.	.348

Table 10: Questionnaire Section 2, Reliability Analysis for Single-user Group

Tests of Normality

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	SingleCoop	Statistic	df	Sig.	Statistic	df	Sig.
MeanPerP_Section1	coop	.228	10	.148	.949	10	.656
	single	.162	10	.200*	.938	10	.528
MeanPerP_Section2	coop	.150	10	.200*	.934	10	.492
	single	.266	10	.044	.897	10	.205

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Table 11: Test of Normality for both Groups and Sections

Descriptives

	SingleCoop			Statistic	Std. Error
MeanPerP_Section1	coop	Mean		3.8688	.12056
		95% Confidence Interval for Mean	Lower Bound	3.5960	
			Upper Bound	4.1415	
		5% Trimmed Mean		3.8681	
		Median		3.8438	
		Variance		.145	
		Std. Deviation		.38126	
		Minimum		3.19	
		Maximum		4.56	
		Range		1.38	
		Interquartile Range		.34	
		Skewness		.134	.687
		Kurtosis		.873	1.334
	single	Mean		3.6125	.10408
		95% Confidence Interval for Mean	Lower Bound	3.3770	
			Upper Bound	3.8480	
		5% Trimmed Mean		3.6250	
		Median		3.6875	
		Variance		.108	
		Std. Deviation		.32914	
		Minimum		3.00	
		Maximum		4.00	
		Range		1.00	
		Interquartile Range		.59	
		Skewness		-.567	.687
		Kurtosis		-.477	1.334
MeanPerP_Section2	coop	Mean		3.8667	.12620
		95% Confidence Interval for Mean	Lower Bound	3.5812	
			Upper Bound	4.1521	
		5% Trimmed Mean		3.8843	
		Median		3.9167	
		Variance		.159	
		Std. Deviation		.39907	
		Minimum		3.08	
		Maximum		4.33	
		Range		1.25	
		Interquartile Range		.65	
		Skewness		-.620	.687
		Kurtosis		.089	1.334
	single	Mean		3.7833	.09558
		95% Confidence Interval for Mean	Lower Bound	3.5671	
			Upper Bound	3.9996	
		5% Trimmed Mean		3.7963	
		Median		3.8750	
		Variance		.091	
		Std. Deviation		.30225	
		Minimum		3.17	
		Maximum		4.17	
		Range		1.00	
		Interquartile Range		.50	
		Skewness		-.998	.687
		Kurtosis		.476	1.334

Table 12: Descriptive Statistics for both Groups and Sections

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means							
						Significance				95% Confidence Interval of the Difference	
		F	Sig.	t	df	One-Sided p	Two-Sided p	Mean Difference	Std. Error Difference	Lower	Upper
MeanPerP_Section1	Equal variances assumed	.007	.932	-1.609	18	.063	.125	-.25625	.15928	-.59088	.07838
	Equal variances not assumed			-1.609	17.625	.063	.125	-.25625	.15928	-.59139	.07889
MeanPerP_Section2	Equal variances assumed	.659	.428	-.526	18	.303	.605	-.08333	.15831	-.41593	.24926
	Equal variances not assumed			-.526	16.769	.303	.606	-.08333	.15831	-.41769	.25102

Table 13: Independent Samples t-test for Equality of Means

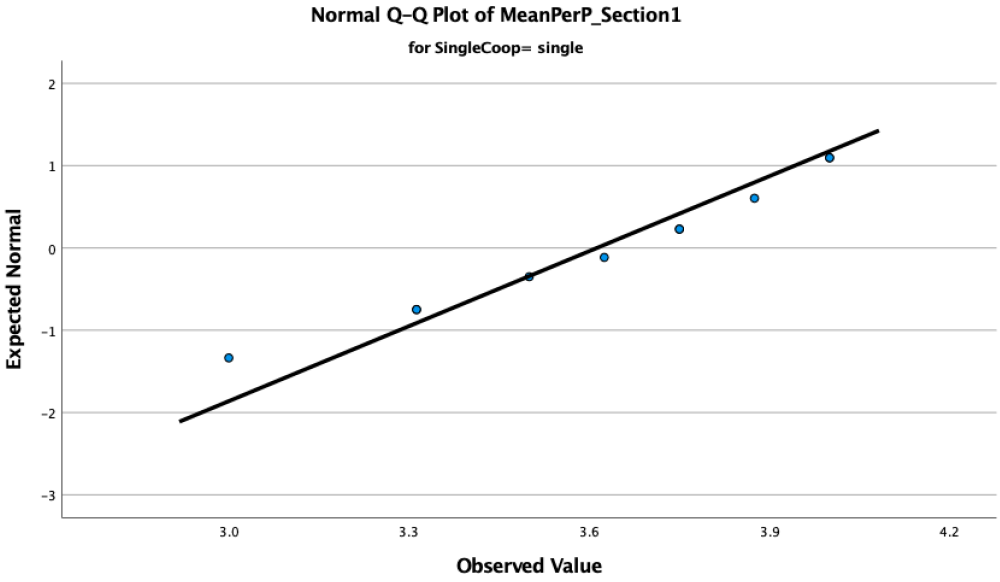

Figure 22: Normal Q-Q Plot on the Mean Score, Single-group, Section 1

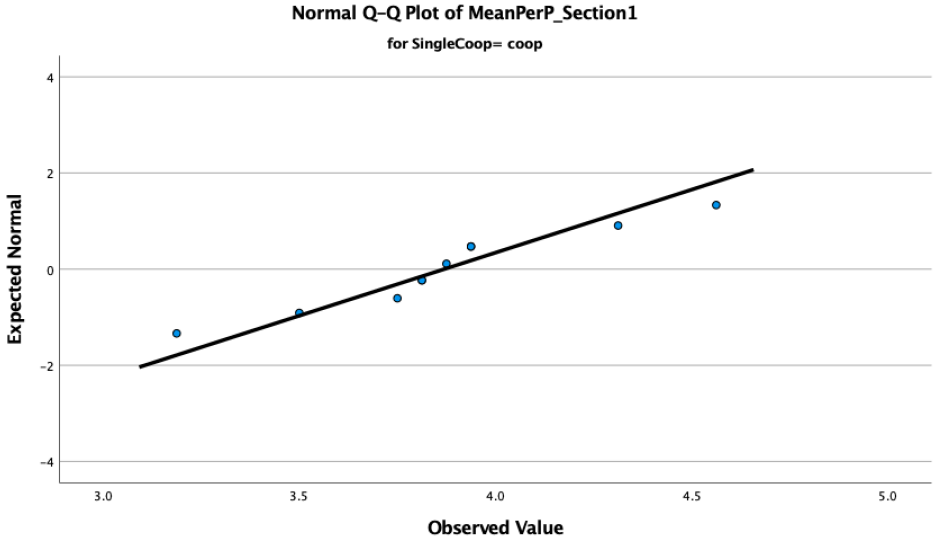

Figure 23: Normal Q-Q Plot on the Mean Score, Multi-group, Section 1

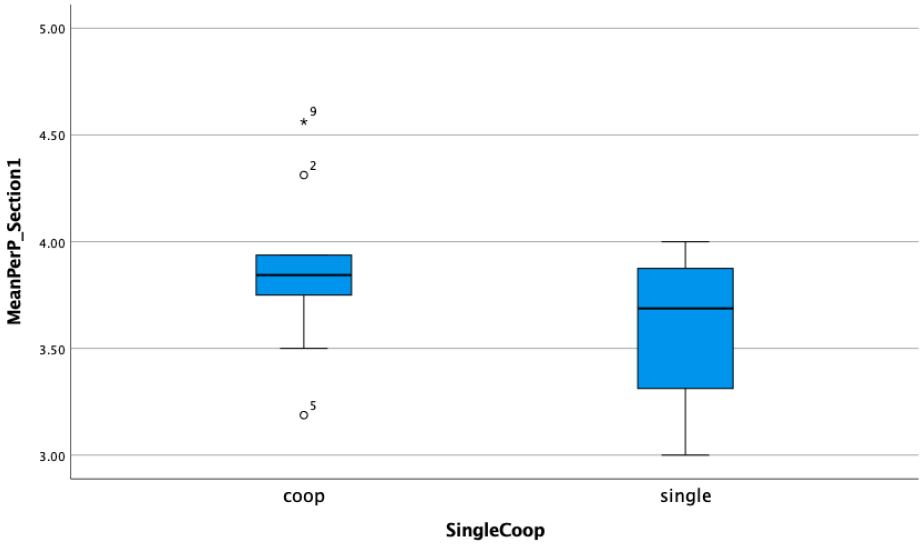

Figure 24: Boxplots on the Mean Score per Participant of Section 1

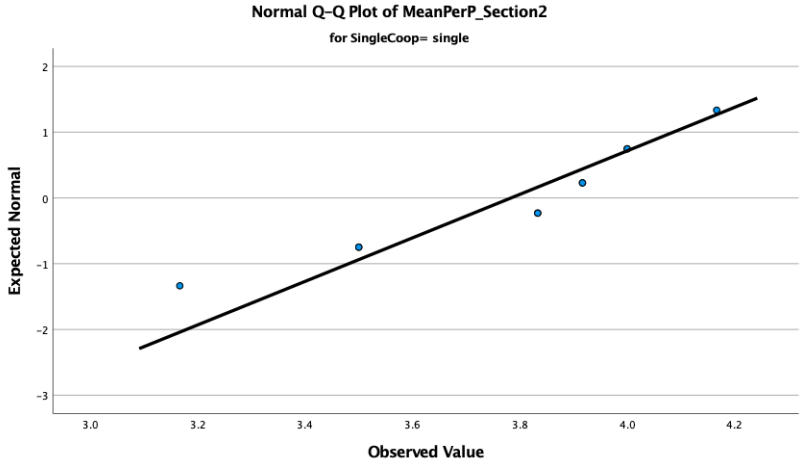

Figure 25: Normal Q-Q Plot on the Mean Score, Single-group, Section 2

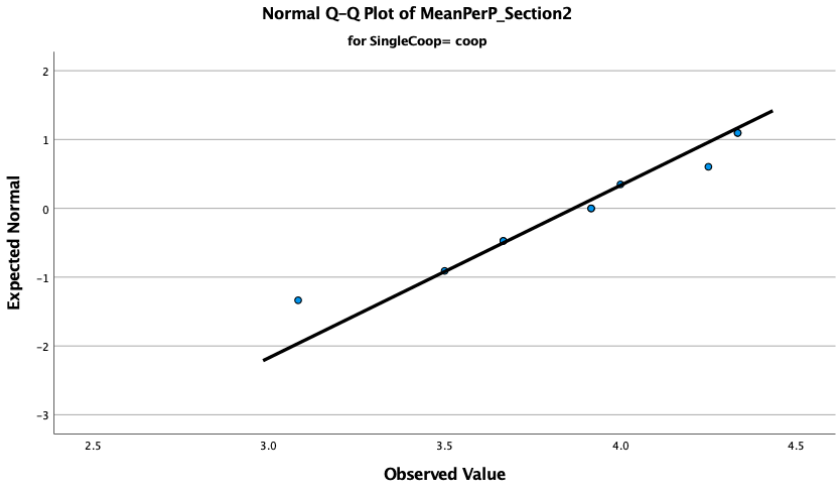

Figure 23: Normal Q-Q Plot on the Mean Score, multi-group, Section 2

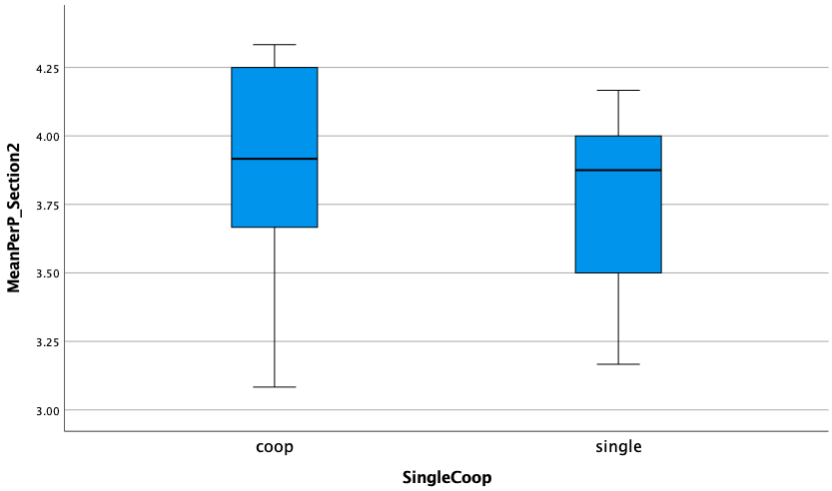

Figure 24: Boxplots on the Mean Score per Participant of Section 2

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means							
						Significance				95% Confidence Interval of the Difference	
		F	Sig.	t	df	One-Sided p	Two-Sided p	Mean Difference	Std. Error Difference	Lower	Upper
S1Q1	Equal variances assumed	.099	.756	.000	18	.500	1.000	.000	.424	-.891	.891
	Equal variances not assumed			.000	18.000	.500	1.000	.000	.424	-.891	.891
S1Q2	Equal variances assumed	1.354	.260	.287	18	.389	.777	.100	.348	-.631	.831
	Equal variances not assumed			.287	13.921	.389	.778	.100	.348	-.647	.847
S1Q3	Equal variances assumed	.361	.555	.249	18	.403	.806	.100	.401	-.743	.943
	Equal variances not assumed			.249	17.558	.403	.806	.100	.401	-.745	.945
S1Q4	Equal variances assumed	1.142	.299	-1.616	18	.062	.123	-.600	.371	-1.380	.180
	Equal variances not assumed			-1.616	17.981	.062	.123	-.600	.371	-1.380	.180
S1Q5	Equal variances assumed	.231	.637	-2.250	18	.019	.037	-.600	.267	-1.160	-.040
	Equal variances not assumed			-2.250	16.941	.019	.038	-.600	.267	-1.163	-.037
S1Q6	Equal variances assumed	1.002	.330	.000	18	.500	1.000	.000	.529	-1.112	1.112
	Equal variances not assumed			.000	17.887	.500	1.000	.000	.529	-1.112	1.112
S1Q7	Equal variances assumed	24.511	<.001	-.802	18	.217	.433	-.200	.249	-.724	.324
	Equal variances not assumed			-.802	9.000	.222	.443	-.200	.249	-.764	.364
S1Q8	Equal variances assumed	5.314	.033	-.701	18	.246	.492	-.300	.428	-1.200	.600
	Equal variances not assumed			-.701	15.452	.247	.494	-.300	.428	-1.210	.610
S1Q9	Equal variances assumed	.151	.702	-.221	18	.414	.828	-.100	.453	-1.053	.853
	Equal variances not assumed			-.221	17.974	.414	.828	-.100	.453	-1.053	.853
S1Q10	Equal variances assumed	.156	.698	-1.053	18	.153	.306	-.300	.285	-.898	.298
	Equal variances not assumed			-1.053	16.111	.154	.308	-.300	.285	-.903	.303
S1Q11	Equal variances assumed	10.654	.004	-5.382	18	<.001	<.001	-2.100	.390	-2.920	-1.280
	Equal variances not assumed			-5.382	11.339	<.001	<.001	-2.100	.390	-2.956	-1.244
S1Q12	Equal variances assumed	.235	.634	.000	18	.500	1.000	.000	.525	-1.103	1.103
	Equal variances not assumed			.000	17.544	.500	1.000	.000	.525	-1.105	1.105
S1Q13	Equal variances assumed	.754	.397	.277	18	.392	.785	.100	.361	-.657	.857
	Equal variances not assumed			.277	15.680	.393	.785	.100	.361	-.666	.866
S1Q14	Equal variances assumed	.077	.784	-.647	18	.263	.526	-.200	.309	-.849	.449
	Equal variances not assumed			-.647	17.961	.263	.526	-.200	.309	-.850	.450
S1Q15	Equal variances assumed	3.582	.075	-.318	18	.377	.754	-.100	.314	-.761	.561
	Equal variances not assumed			-.318	15.100	.377	.755	-.100	.314	-.770	.570
S1Q16	Equal variances assumed	.099	.757	.325	18	.374	.749	.100	.307	-.546	.746
	Equal variances not assumed			.325	17.589	.374	.749	.100	.307	-.547	.747

Group Statistics

	SingleCoop	N	Mean	Std. Deviation	Std. Error Mean
S1Q1	single	10	3.70	.949	.300
	coop	10	3.70	.949	.300
S1Q2	single	10	4.50	.527	.167
	coop	10	4.40	.966	.306
S1Q3	single	10	3.70	.823	.260
	coop	10	3.60	.966	.306
S1Q4	single	10	3.40	.843	.267
	coop	10	4.00	.816	.258
S1Q5	single	10	4.00	.667	.211
	coop	10	4.60	.516	.163
S1Q6	single	10	2.20	1.135	.359
	coop	10	2.20	1.229	.389
S1Q7	single	10	4.00	.000	.000
	coop	10	4.20	.789	.249
S1Q8	single	10	3.80	1.135	.359
	coop	10	4.10	.738	.233
S1Q9	single	10	3.10	.994	.314
	coop	10	3.20	1.033	.327
S1Q10	single	10	4.10	.738	.233
	coop	10	4.40	.516	.163
S1Q11	single	10	1.20	.422	.133
	coop	10	3.30	1.160	.367
S1Q12	single	10	3.40	1.075	.340
	coop	10	3.40	1.265	.400
S1Q13	single	10	3.80	.632	.200
	coop	10	3.70	.949	.300
S1Q14	single	10	4.30	.675	.213
	coop	10	4.50	.707	.224
S1Q15	single	10	4.40	.843	.267
	coop	10	4.50	.527	.167
S1Q16	single	10	4.20	.632	.200
	coop	10	4.10	.738	.233

Table 14: Item-wise t-test for Equalities of Means and Item-wise Statistics, Section 1

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means							
						Significance				95% Confidence Interval of the Difference	
		F	Sig.	t	df	One-Sided p	Two-Sided p	Mean Difference	Std. Error Difference	Lower	Upper
S2Q1	Equal variances assumed	10.756	.004	-1.633	18	.060	.120	-.400	.245	-.915	.115
	Equal variances not assumed			-1.633	12.462	.064	.127	-.400	.245	-.932	.132
S2Q2	Equal variances assumed	2.359	.142	-.739	18	.235	.470	-.200	.271	-.769	.369
	Equal variances not assumed			-.739	15.898	.235	.471	-.200	.271	-.774	.374
S2Q3	Equal variances assumed	3.948	.062	-.450	18	.329	.658	-.200	.445	-1.134	.734
	Equal variances not assumed			-.450	12.375	.330	.661	-.200	.445	-1.166	.766
S2Q4	Equal variances assumed	2.406	.138	.000	18	.500	1.000	.000	.497	-1.043	1.043
	Equal variances not assumed			.000	16.775	.500	1.000	.000	.497	-1.049	1.049
S2Q5	Equal variances assumed	2.396	.139	-.383	18	.353	.707	-.200	.523	-1.298	.898
	Equal variances not assumed			-.383	14.353	.354	.708	-.200	.523	-1.319	.919
S2Q6	Equal variances assumed	3.627	.073	3.488	18	.001	.003	1.300	.373	.517	2.083
	Equal variances not assumed			3.488	13.983	.002	.004	1.300	.373	.501	2.099
S2Q7	Equal variances assumed	.006	.938	1.282	18	.108	.216	.500	.390	-.320	1.320
	Equal variances not assumed			1.282	17.787	.108	.216	.500	.390	-.320	1.320
S2Q8	Equal variances assumed	.	.	.000	18	.500	1.000	.000	.236	-.495	.495
	Equal variances not assumed			.000	18.000	.500	1.000	.000	.236	-.495	.495
S2Q9	Equal variances assumed	.654	.429	-.818	18	.212	.424	-.300	.367	-1.070	.470
	Equal variances not assumed			-.818	17.999	.212	.424	-.300	.367	-1.070	.470
S2Q10	Equal variances assumed	.067	.799	-.318	18	.377	.754	-.100	.314	-.761	.561
	Equal variances not assumed			-.318	17.998	.377	.754	-.100	.314	-.761	.561
S2Q11	Equal variances assumed	.639	.434	-1.769	18	.047	.094	-.700	.396	-1.532	.132
	Equal variances not assumed			-1.769	17.269	.047	.095	-.700	.396	-1.534	.134
S2Q12	Equal variances assumed	1.728	.205	-1.976	18	.032	.064	-.700	.354	-1.444	.044
	Equal variances not assumed			-1.976	13.525	.034	.069	-.700	.354	-1.462	.062

Group Statistics

	SingleCoop	N	Mean	Std. Deviation	Std. Error Mean
S2Q1	single	10	4.50	.707	.224
	coop	10	4.90	.316	.100
S2Q2	single	10	4.50	.707	.224
	coop	10	4.70	.483	.153
S2Q3	single	10	3.90	1.287	.407
	coop	10	4.10	.568	.180
S2Q4	single	10	2.70	.949	.300
	coop	10	2.70	1.252	.396
S2Q5	single	10	2.30	.823	.260
	coop	10	2.50	1.434	.453
S2Q6	single	10	3.20	1.033	.327
	coop	10	1.90	.568	.180
S2Q7	single	10	4.20	.919	.291
	coop	10	3.70	.823	.260
S2Q8	single	10	4.50	.527	.167
	coop	10	4.50	.527	.167
S2Q9	single	10	3.70	.823	.260
	coop	10	4.00	.816	.258
S2Q10	single	10	4.50	.707	.224
	coop	10	4.60	.699	.221
S2Q11	single	10	3.50	.972	.307
	coop	10	4.20	.789	.249
S2Q12	single	10	3.90	.994	.314
	coop	10	4.60	.516	.163

Table 15: Item-wise t-test for Equalities of Means and Item-wise Statistics, Section 2