BACHELOR THESIS

Improving the engagement and experience of museum visitors by means of EEG and interactive screens of VidiNexus

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Abstract

The main goal of this research is to explore options to improve the experience and engagement of museum visitors by developing a prototype including Brain-Computer interfaces (BCI) and the interactive screens of client VidiNexus. This is done by following a methodology that is focused on three different aspects of the research; Museum & Art, BCI, and the prototype. The first two aspects are the focus of the background literature research. The findings are used to guide the creative process of the prototype development in the right direction. A prototype of the system, including an interactive quiz, matches visitors to artworks based on choices and engagement levels measured by an EEG device. This prototype was created during the ideation, specification, and realization phase of the research; and tested in the evaluation phase.

In conclusion, the prototype that has been developed and tested proves that the concept for an art-visitor feedback system is feasible. The tests showed that is technically possible to realise such a working prototype of such a system. The positive feedback from the users showed that the prototype added value to the users, as it improved their engagement and they learned more about several art aspects. Results of the user tests showed that the prototype is able to improve the experience and engagement of participants. The prototype is described as fun and intriguing and participants were excited about the fact that their brainwaves were part of the matching process. Additionally, almost all participants would recommend the system to others if it was placed inside a real museum. However, before the system can be placed inside a real museum, adjustments to the quiz, the equipment, and the art database have to be made.

Acknowledgments

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Chapter 1: Introduction

1.1 Introduction and problem description

Most of the museums in the Netherlands have little or no interaction with their visitors. A traditional museum visit exists of watching art and reading some information about it [1], which includes no interaction at all. According to Campos et al. [1] museum visitors nowadays expect to learn while also having fun. Additionally, Abdelrahman et al. [2] argue that the main experience a visitor has of a museum is shaped by their behavior based on their interests and engagement in the museum. Therefore interactive museum exhibits, where visitors can change a situation based on their own input and which supports social interactions sparks lots of interest from the visiting audience [3]. In conclusion, sources [1], [2], [3] agree with the fact that museums should implement more interactivity with their visitors.

Interaction is not the only aspect of a museum that could be improved. Another aspect is that generally, museums do not adapt to the times. With technology rising and the development of many technological applications within houses, schools and public spaces, museums cannot stay behind if they want to stay relevant for visitors [4] Technology provides lots of new possibilities to approach museum visitors [1] and museums should implement new technologies to enhance the experience of visitors. Additionally, Baraldi et al. [5] argue that museums lack an instrument that provides entertainment, instructions and visit personalization in an effective and natural way.

However, Campos et al. [1] argue that many art museums are struggling to implement innovative and technological approaches to engage the visitors in their exhibitions. Mainly because it is of great importance that the technological applications meld seamlessly in the museum environment [1]. In this way, visitors do not think of the application as an independent computer but as part of the museum exhibition.

Two smart technologies might support museums in their struggle for more interaction with their visitors: interactive screens and brain-computer interfaces (BCIs). These two technologies are further elaborated in the following paragraphs.

A company that creates interactive screens to provide engagement for users is VidiNexus. VidiNexus is the client of this research and a company placed in Hengelo [6]. Founders of VidiNexus are Jaap Reitsma and Maurice Markslag. The company provides interactive social screens for museums, events, offices, and shops [6]. The interactive screen is called EXPOmatic. It can show photos, videos, flyers, or social media on a continuous basis. It supports almost all popular social media and additionally, any document can be shared with the visitors through Dropbox [6]. The goal of VidiNexus is to enhance the visitors' journey with the help of these interactive screens. VidiNexus already accomplished this for all different kinds of clients. For example; World Trade Center, Robeco, MuseumFabriek, and Historisch centrum Overijssel [6] The same interactive screens are used as an interaction tool in this research to provide an interaction between the visitors and the museum.

Figure 1: The EXPOmatic interactive screen of VidiNexus [6]

Another possibility of implementing interaction technology inside a museum to improve the visitors' engagement is by using Brain-Computer Interfaces (BCI) to provide personal and real-time feedback. BCI's are systems that can translate a user's brain activity into commands for an interactive application or use the brain activity to alter the application [3]. For example, a system that can move a ball to the left or right of the screen with the input of the user only thinking of left or right-hand movements. Furthermore, BCI systems are becoming more and more popular outside the medical sector. The scope is expanding and nowadays lots of other BCI applications are being developed to use in the entertainment industry [3], [7]. BCI systems could be valuable for this project because these systems are able to measure engagement levels to give real-time personal feedback, which could improve the interaction between the user and the museum. Additionally, the data a BCI system obtains could be used to measure, analyze and interpret visitors' responses toward art. When these responses are known, improvements may be made to the exhibition. So, newly developed BCI systems may help improve the engagement and experience of users during their visit.

To conclude, with the growing interest in interaction technology between humans and computers and the rapid increase in the use of smart technologies, there is a great need for museums (amongst other things) to implement new technologies like BCI [3]. Therefore, this research focuses on implementing BCI together with the VidiNexus screen inside museums to improve the engagement and experience of visitors. The right balance between art, technology, and interaction needs to be researched.

1.2 Research questions

The purpose of this research is to find out what influences the experience of visitors in a museum and how this experience could be improved by using smart technologies, such as BCI systems and the interactive screens of VidiNexus. Therefore, the following main research question is defined:

> *How can a Brain-Computer Interface system in combination with interactive screens improve the engagement and experience of museum visitors?*

This research question is answered by investigating multiple sub-questions. These sub-questions are divided into two topics; Museum & Art and BCI. This is done to separate the museum part of the research from the more technical part with BCI. When these topics are discussed separately, combinations of the main findings can be explored for the final part of the research, which consists of developing and testing a prototype system. The sub-questions can be found below.

Sub-questions about Museum & Art:

This part of the research focuses on the experiences, goals, and needs of the museum itself and the museum visitors. This provides insights about the aspects that could be improved, which are needed to answer the main research question.

- *What are the main goals of an art museum and museum visitors?*
- *How do visitors experience an art museum and the art displayed?*
- *Which emotional responses have visitors towards art?*
- *What features can positively enhance the visitors' experience in a museum?*

Sub-questions about BCI:

This part of the research reflects the capabilities of a BCI system that can be used to answer the main research question. Furthermore, methods need to be explored how BCI systems work and how it may improve the experience and engagement inside a museum.

- *How can one measure engagement using a BCI?*
- *What are the different steps that need to be taken to transform raw sensor data into useful commands?*
- *How can a BCI system be used to improve the interaction inside a museum?*

Sub questions prototype:

At the end of the research, the aim is to have a prototype of an interactive system that improves the engagement and experience of visitors inside a museum. The prototype incorporates the best fitting BCI system and gives users real-time feedback. The prototype is tested, evaluated, and adjusted when deemed necessary. Experiences with the prototype are used to answer the main research question on improving the interaction between a museum and its visitors with smart technologies.

- *What is the most promising concept using BCI and interactive screens to improve the user experience and engagement?*
- *What are the user experiences of the final concept?*

1.3 Scope of the research

The research scope is defined by the smart technologies of the client company and the University of Twente. Furthermore, museums are selected and the timeline is presented.

As stated in the introduction, VidiNexus is a company in Hengelo that provides interactive screens for events, buildings, museums, and shops [6]. With their screens, VidiNexus wants to enhance the journey of the visitors [6]. During this research, a VidiNexus screen is available to implement in the final project. Furthermore, there are limitations in the usage of BCI. Namely, this is limited to the sensors available at the University of Twente in the BCI test bed. Other sensors are not included in the research.

Additionally, the scope of this research is limited to public art museums in The Netherlands. The target group of this research is not yet determined. This is because it depends on the results of the state of the art research and the interviews with Dutch museums. Finally, this research needs to be done within 10 weeks. Therefore the scope of this research stays within the boundaries of possibilities of 10 weeks.

1.4 Methodology

To answer the main research question, the sub-questions within the topics need to be answered first. The schematic overview displayed in *Figure 2* shows which subtopics are answered in which chapter. As can be seen, the State of the Art chapter includes literature research and interviews. This information is used to get answers to the first two subtopics. The chapter's ideation, specification, realisation and evaluation are focused on the third topic; Prototyping. The information gathered in the State of the Art is used to guide the creative process. Furthermore, the evaluation phase starts focusing on the main research question and provides a proof of concept. Finally, the conclusion combines the results of the part researches to get an overall conclusion on the main research question.

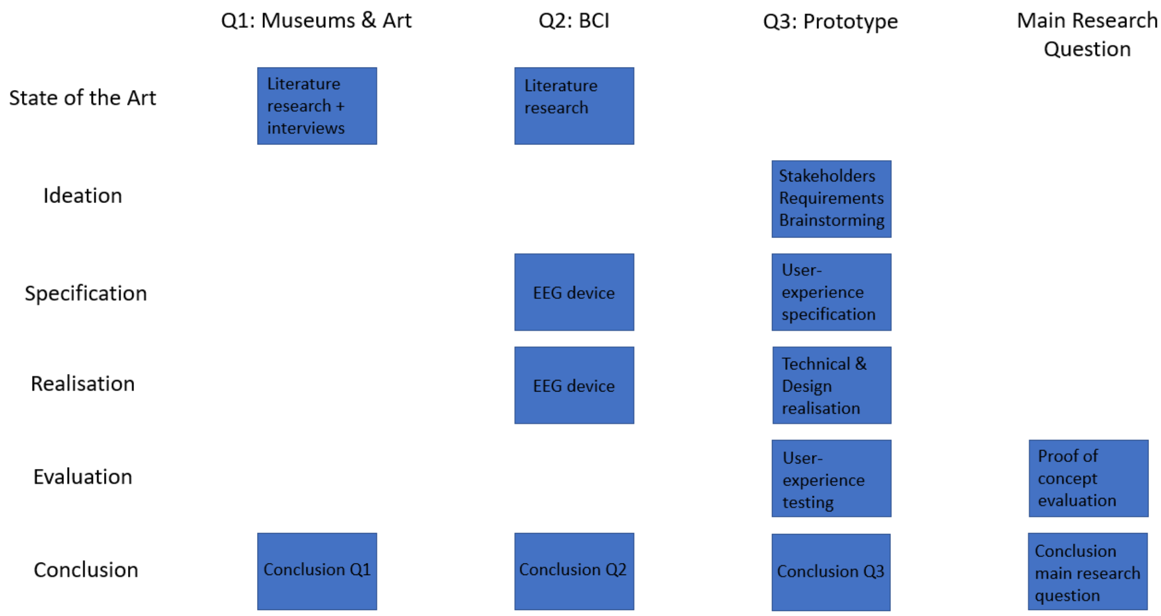

Figure 2: The methodology schematic of the entire research

1.5 Structure of the report

This research starts with State of the Art research in *Chapter 2*. This chapter focuses on the first two topics in this research and reflects the present state of scientific or engineering development. Additionally, interviews with stakeholders are be covered. The information gathered during the State of the Art, is used in the third chapter; 'Ideation'. This chapter focuses on brainstorming. The brainstorm ideas are further elaborated in the fourth chapter 'Specification' and the final concept is realised in the fifth chapter of the research 'Realisation'. After the realisation of the prototype, user experience testing and evaluation of the results are discussed in *Chapter 6.* The conclusion of the research in *Chapter 7* is based on the user testing results and the other findings during the research. Finally, recommendations for further research are stated in *Chapter 8.* The appendices contain intermediate results of the research.

Chapter 2: State of the art research

This chapter includes state of the art research, which reflects the present state of scientific or engineering development. Because this research has a lot of different aspects to it, the state of the art is divided into sections. Each section focuses on a more specific topic of the total research.

Insights for the state of the art research are collected in several ways. Firstly, insights are gathered by research in (literature) articles and books. These articles come from websites such as Scopus and Google Scholar. The books are borrowed from the library or accessed online via Scopus and Google Scholar. Additionally, websites, journals, and videos are used to get a wide view of the researches that are already done. Furthermore, interviews and surveys are conducted to get primary data about the needs of the users, museums, and the client. These methods add valuable extra information about underlying thoughts and specific topics within this research. The interviews and surveys are conducted after the Ethical Committee of the University of Twente had approved the protocol.

2.1 Museums & Art

This section is about the current status of museums and the perception of art. Museums can be classified into different categories. The three main categories are modern art museums, historical museums, and science museums (Interview, *Section 2.5.1*). The main goals of a museum are to inspire, entertain and educate visitors (Interview, *Section 2.5.1*). This section is about the way people experience art and about the level of interaction that is implemented inside a museum. These specific topics are interesting for this research because they both have a great impact on the visitors' experience inside a museum.

2.1.1 Visitor experiences of art

What is considered art differs with time and from person to person. According to Leder et al. [8] the borders of what was considered an artwork once and what is called art today are changing due to the introduction of video and online art. Despite these changes, the factors on how people respond towards art do not change [8]. Examples of these factors are the environment in which the art is presented or the personal affection for the artwork. This can have a huge impact on the experience people have of art [8]. These factors are explained in the following sections.

Environment

Brieber et al. [9] have done research towards the effects of the environment on the perception of art. They have tested the same artworks in a laboratory environment and a museum environment. Brieber et al. [9] have discovered that art inside a real museum environment received a higher effect of aesthetic appreciation and visitors liked the artwork more. After doing more experiments, they have found that not only the environment matters but also the time spent looking at artworks. The longer visitors look at an item, the higher the art experience was. People inside the museum environment spend, by themselves, more time looking at artworks than the people inside the laboratory environment. This also contributed to a better experience of the art inside the museum environment [9].

Another research, done by Leder et al. [8], have the same results about environmental effects. However, they have found that if the research is done in a laboratory but it is explicitly stated that the visitors are participating in an experiment, the effects of the environment are smaller [8].

Aesthetics

The next factor that has an impact on the experiences of art is aesthetics. Leder et al. [8] have made an extensive model about the aesthetic experience of visitors inside a museum or gallery. This model is of relevance for this research because it shows different aspects that influence the experience of art inside a museum. These aspects need to be known, to be able to improve the museum experience. This model can be seen in *Figure 3.*

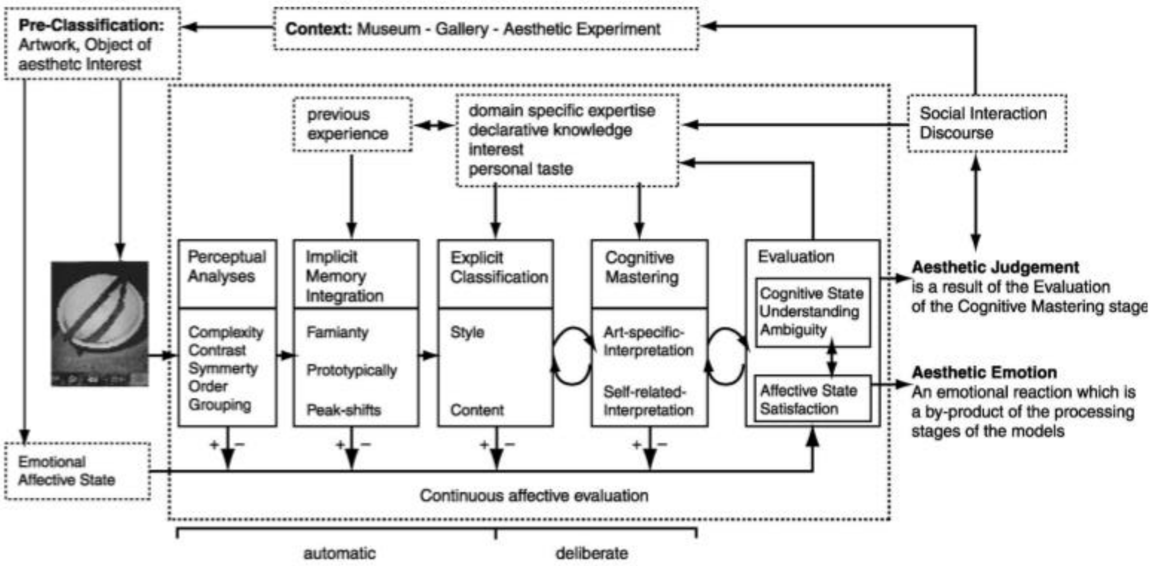

Figure 3: A model of aesthetic experience by Leder et al. [8]

The main elements in the model are perceptual analyses, implicit memory integration, explicit classification, cognitive mastering, and evaluation. These elements can be found in the middle of *Figure 3* from left to right. The first block is perceptual analyses. The perceptual analyses of an artwork for visitors happens quickly without any effort [8]. In this phase, visitors notice contrasts, complexity, symmetry, and order inside the artwork.

The second stage 'implicit memory integration', depends on memory effects of the visitor. Leder et al. [8] state that the aesthetic preferences are affected by familiarity. A visitor is more attracted to the artwork if, for example, the artist is familiar with the visitor. Leder et al. [8] have done an experiment in which they connected a painting with the famous artist van Gogh. This led to positive correlations with the aesthetic judgement of the visitors. However, as soon as Leder et al. [8] introduced the painting as fakes, these positive correlations were strongly reduced. Canning [10] agrees with this effect. She states that the affect visitors have on art is depended on the connections that support the engagement of visitors [10]. To conclude this second stage, the aesthetic experience depends on familiarity for the visitor.

The third aspect of the model is explicit classification. At this stage, processing is particularly affected by the expertise and knowledge of the visitor [8]. The analyses of this stage are connected with content and style. Artworks have a positive effect on the visitor when the expertise about the artwork, the historical importance, or the artist increases. This is may be of importance for the graduation project because it means the experience can be higher if more information about the artwork is available.

The fourth and fifth aspect of the model is 'cognitive mastering' and 'evaluation'. These two processes are very closely connected to each other. According to Leder et al. [8] it is very important to understand the features of art when art provides a need for interpretation. If this is done successfully, this is experienced as emotionally positive. Additionally, if the artwork is understand by the visitor, the result is that the rewarding centers of the brain are activated, which also improves the experience [8]. During the evaluation process, personal taste has an important role in affecting aesthetic experiences. Also, ambiguity is appointed by Leder et al. [8] as a measurement that influences the experiences during the evaluation process.

The outputs of the model are aesthetic judgement and aesthetic emotion. According to Leder et al. [8] the aesthetic emotion depends on the success of information processing. For example, asking how pleasing an artwork was, is related to the aesthetic emotion. Aesthetic judgement is based on what someone thinks of the artwork [8]. This is closely related to aesthetic emotion, but the difference becomes more clear with the help of an example. When an experienced visitor decides that a painting is a poor example of a certain painter, the aesthetic judgement is low. However, the process of coming to that decision could still feel rewarding. The more experienced a visitor is in looking at art, the clearer the distinction between aesthetic judgement and aesthetic emotion can be made.

At the end of the research, Leder et al. [8] give some recommendations and disclaimers. Firstly, the model is not yet tested a lot. Therefore, Leder et al. [8] state that testing and refinement needs to be done to determine and improve the accuracy of the model. Furthermore, they argue that the outcomes (aesthetic emotion and judgement) diverge in different situations. Therefore, the interdependence between pleasure, interest, and affective judgements needs to be explored in future research [8].

However, Leder et al. [8] are not the only people who have researched this topic. A completely different approach to model aesthetic experiences is done by Konston et al. [11]. They have studied the brain responses to art with EEG to discover the basis of aesthetic experiences. A 32 channel EEG headset is used to discover different parts of the brain that are active during an aesthetic experience caused by artworks. To analyse the aesthetics of an art image, the approach of Konston et al. uses four features; luminance, texture, gradient, and composite features [11]. The luminance is analogous to the brightness of the artwork. The texture is a feature that examines the brushwork of the artist. The gradient maps the rate of change in intensities. The composite features are the grey levels of each segmented block inside the image. Unfortunately, the approach of Konston et al. [11] only reached an accuracy of 55%.

2.1.2 Visitor interactions inside museums

As also mentioned in the introduction, lots of museums in the Netherlands have little or no interaction with their visitors. A traditional museum visit exists of watching art and reading some information about it [1], which includes no interaction at all. Even when, according to Campos et al. [1] museum visitors nowadays expect to learn while also having fun. This is often not achieved if the museum has no or little interaction with its visitors.

Furthermore, Abdelrahman et al. [2] argue that the main experience a visitor has of a museum is shaped by their behavior based on their interests and engagement in the museum. Therefore interactive museum exhibits, where visitors can change a situation based on their own input and which supports social interactions sparks lots of interest from the visiting audience [3]. Additionally, Baraldi et al. [5] argue that museums lack an instrument that provides entertainment, instructions, and personalization effectively and naturally.

Campos et al. [1] have stated a possible reason for the lack of interactivity inside a museum. They argue that many art museums are struggling to implement innovative and technological approaches to engage the visitors in their exhibitions [1]. Mainly because it is of great importance that the technological applications meld seamlessly in the museum environment [1] In this way visitors do not think of the application as an independent computer but as part of the museum exhibition. If the system is part of the museum exhibition, visitors are more tented to use and like the system. Because museums are struggling to meld the installation in the museum environment properly, they do not implement it at all.

Another difficulty, also stated by Campos et al. [1], is that interactive installations are difficult to prototype or to test in the early prototype stages. This could be a difficulty because the lack of prototyping and testing often results in a product of lesser quality [1]. So, when a museum does decide to have an interactive system, but the system does not perform as it should (for example, by the lack of prototyping and testing) the museum could decide to stop the interactive installation. For a museum, one bad experience could even lead to postponing the implementation of interactive installations again (Interview The MuseumFabriek, *Section 2.5.1*). These two difficulties may be part of the reason why there is little interaction inside a museum.

2.2 Brain-Computer Interfaces (BCI)

In recent years, brain-computer interfaces (BCI) have become more and more popular [7]. By the common effort of scientists, communication between humans and computers through BCI systems is possible. BCI can be described as a system that translates a measure of a user's brain activity into messages or commands for an interactive application [3]. This allows a BCI system to completely or partially replace devices like for example a computer mouse or computer keyboard [12].

BCI systems could be valuable for this project because these systems are able to give real-time personal feedback which could improve the interaction between the user and the museum. Additionally, the data a BCI system obtains could be used to measure, analyze and interpret visitors' responses toward art. If these responses are known, improvements can be made. Therefore, newly developed BCI systems may help improve the engagement and experience of users during their visit. However, BCI has more to offer for a museum. BCI is a new and, for many people, exciting technology. Having an interactive BCI system inside a museum could also attract more visitors.

2.2.1 BCI systems

BCI's can be invasive and non-invasive. Invasive means that it requires surgical placements of electrodes on, or in, the brain. These electrodes will record brain activity. Invasive BCI is (until now) only used for medical applications. Non-invasive BCI means that it does not require surgical placement of the electrodes. The sensors can be places on the skin itself, for example on the scalp. Non-invasive recordings can be divided into two methods; direct measurements and indirect measurements [3]. According to Nam et al. [3] direct measurements detect the electrical or magnetic activity of the brain, such as EEG. Indirect measures of the brain reflect the metabolism or hemodynamics of the brain. This does not directly characterize the neuronal activity [3].

In *Figure 4* an overview of BCI sensor methods can be found. As can be seen in the figure, a distinction between direct and indirect methods is made. For this research, the focus is on direct methods, which can be seen on the left side of the graph. On the right side of *Figure 4*, the hardware complexity and price of direct and indirect methods are shown. As can be seen, EEG is classified as lowest complexity and price. Therefore, the main focus is on direct non-invasive EEG recording methods.

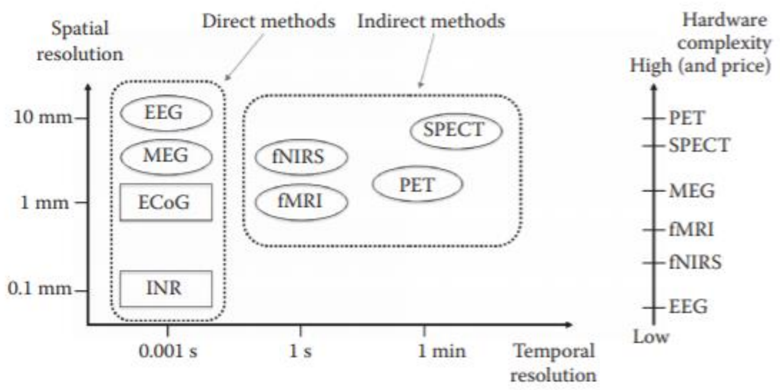

Figure 4: Different BCI measurement methods [3]

Even with the main focus on non-invasive EEG recording methods, there are still lots of choices to be made. Prpa & Pasqueir [13] have made a more extensive overview of a basic BCI device to display these choices. This overview shows, for example, the choices that need to be made about different types of electrodes and types of output data. The overview can be seen in *Figure 5*.

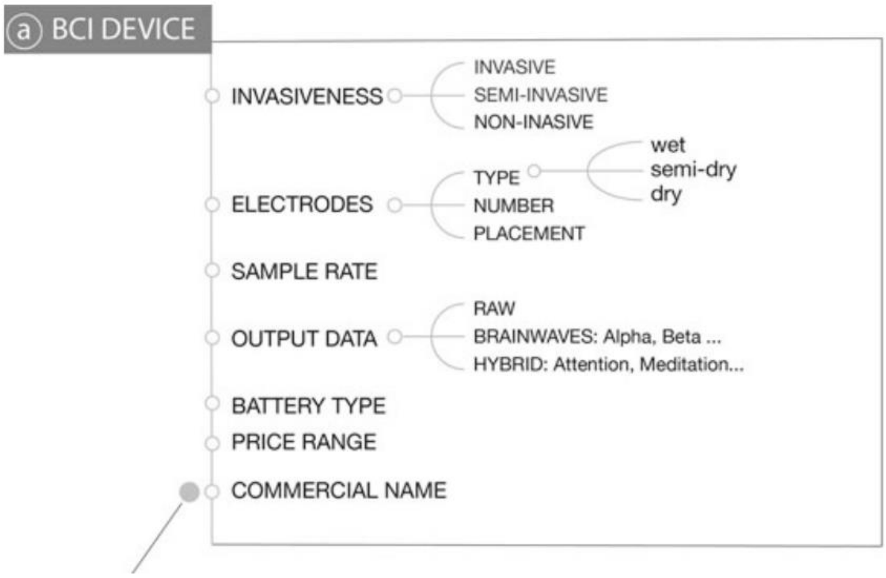

Figure 5: Overview of BCI device choices [15]

As can be seen in *Figure 5*, the output data of a BCI system can be divided into three groups; raw data, brainwave data, and hybrid data [13]. According to Nijholt [14], these three groups can be used in an interactive application in two ways; control by affective state and issuing commands by brain signals. Control by affective state uses the output data to increase or decrease the task load or information flow [14]. According to Nijholt, this could provide pleasant and effective feedback which keeps the user interested. The second way, issuing commands by brain signals, uses the output data to control the interactive application itself. For example, the mental state or emotion of the user can be used as input for the game [14].

2.2.2 BCI in the entertainment industry

The entertainment industry has opened a way to use BCI applications in the non-medical sector. When BCI is used in the entertainment sector, the robustness and efficiency that is needed in the medical sector are not always needed anymore [7]. This implies that efficiency is not the main goal or concern of BCI when implementing this in the entertainment industry. According to Nijholt [7] the goal switched more to affect, comfort, community, and playfulness.

More and more games with implemented BCI are being developed. For example, Bonnet et al. [15], created a multi-user video game called BrainArea. This game is a simple football game in which the users can play together or against each other. The users can score a goal by using the EEG attached to their heads. Furthermore, Nam et al. [3] have developed a Brainball game that intends to drops the stress level of users. The game can only be won if the users relax. In this way, the user will learn how to control stress while being in an amusing situation [16]. Another application that Nam et al. [3] have developed is AlphaWow. This game uses the EEG activity to detect the emotional state and stress levels of the user and adapts the avatar's form accordingly. In short, EEG measurements can be used for interactive systems and can connect the level of stress and the emotional state of a person.

Next to making new applications to implement BCI, researchers are also combining existing games with brain controlling functions, to provide a multi-brain entertainment experience [16]. For example, Scherer et al. has developed the Graz-BCI game controller. This controller is able to connect any BCI input (for example EEG Emotiv headset) to the online game; World of Warcraft [15]. This is important information for this research because it shows that EEG methods can also be connected with already existing interactive systems. This means that also already existing interactive systems can be used for the final system.

2.2.3 BCI to improve the user engagement in museums

Application to improve the user experience and engagement inside museums based on BCI already exists. For this research, it is important to know what is already done, what elements achieved positive effects, and how the applications improved the engagement of visitors. This section reviews already existing BCI applications and shows the advantages and disadvantages of these applications.

The first application that is discussed tries to improve the user engagement of visitors by adjusting specific features based on the visitors' preferences. Abbattista et al. [17] have used BCI to explore if an exhibition piece is of interest to a visitor. This is done with EEG signals captured by a low-cost EEG headset, which only uses one electrode and is developed by the company Neurosky. Despite that this causes the accuracy to be limited, the size and comfort of the low-cost EEG device allow for real-time assessment [17]. In the beginning, the user is asked to relax for 10 seconds, to create a baseline measurement. Then, the images of the artworks are shown for 10 seconds. After this, the user should fill in an evaluation form where the user was able to choose between three options, interested, neutral, or not interested. The evaluation form is used to measure the accuracy, which resulted in an average of 75%. Abbattista et al. [17] used the previously obtained data to study the feasibility of a real-time predicting system. The system chooses the next artwork based on the measurements during the previously showed artworks. When confirming the choices of the system with the opinions of the users, it matched 70% of the cases. In the end, Abbattista et al. state that the system has high potential to improve user engagement in a museum [17].

Similar research is done by Abdelrahman et al. [2]. The system Abdelrahman et al. [2] have developed gives real-time feedback and suggestions to the visitor to personalize the visitors' experience. At the entrance of the museum, visitors were presented a selection of photographs showing exhibited items. By the means of BCI, the level of engagement was measured. This was done with the Emotiv EPOC that the visitors wore during the questions. In the beginning, the visitor was asked to relax for 60 seconds with their eyes closed. This was done to create a baseline EEG signal, which was used for comparison. After relaxation, the different exhibited items were shown for 20 seconds. Depending on the measured level of engagement per exhibited item, a starting point for a personalized museum tour was announced. Additionally, the visitor received extra feedback on their mobile phones recommending other exhibit items that may match the same engagement levels. To conclude, the main feature of the system of Abdelrahman et al. [2] was that visitors received a personal route through the museum based on engagement level measured via the Emotiv EPOC at the entrance of the museum. This system has a disadvantage that families or groups who together join the museum, can be separated because members have a different starting point [2].

The difference between the first application of Abbattista et al. [17] and the second application of Abdelrahman et al. [2] is that the first application only adjusts the visitors' preferences during the visit. The second application already begins selecting preferences at the entrance via an interactive screen. There are no results given about which procedure works the best. Furthermore, there are also some aspects on what the two sources agree on. They both agree that the application does not only help the visitor but is also very useful for the museums themselves. By knowing the preferences of the visitors, the museums get a better view of how to attract more visitors and are able to satisfy the needs of a diverse audience [2], [17].

Where Abdelrahman et al. [2] have used the BCI system mainly at the entrance of the museum, Banzi and Fulgieri [18] used a BCI system at the end of a museum visit. They have done research on the relation between the engagement level of visitors inside museums and previous received visual stimuli. The participants were divided into two groups, one group that received specific visual stimuli before visiting the museum, while the other group did not receive visual stimuli. Both groups received the same questions afterward. While the participants answered the questions, the brainwaves of the participants were measured with the NeuroSky headset. Banzi and Fulgieri choose the EEG Neurosky headset instead of the Emotiv EPOC due to the easiness of positioning the device [18]. For evaluating the brainwaves, multiple MATLAB functions were used. At the end of the research, Bansi and Fulgieri concluded that the visual stimuli worked; the EEG measurements of the group that received the visual stimuli showed a higher attention and engagement level at the questions that the stimuli were about. This is compared with the other group that did not receive any visual stimuli before the visit [18].

2.3 Electroencephalogram (EEG)

As stated in a previous section (*Section 2.2.1*), EEG can be a direct non-invasive recording method [3]. However, there are more aspects of EEG that need to be explored, before it can be used for this research. For example, for this research, it is important to gain insight into the EEG measurements and different available EEG systems. These two aspects are explained in this chapter.

2.3.1 EEG measurements

EEG measurements are objective measurements. This means that the measurements are based on how people perform a task [19]. Fahrenfort [19] states that this is irrespective of what they experience while performing the task. So, evaluating an interaction by asking users about the experience is a subjective measurement, while measuring or observing the interaction is an objective measurement. Therefore, EEG devices deliver objective measurements.

There are multiple reasons why researchers argue that EEG is a good objective method for measuring emotions. To start, Liu & Fu [20] state that consciously manipulating the signals that EEG detects is almost impossible. Yang et al. [21] and Bidgoly et al. [22] agree with that. Additionally, they all argue that in comparison to other recognition techniques, such as facial expression, speech recognition, or body posture, EEG is the most reliable. Think of for example a 'poker face', in which almost no emotion can be seen. EEG is able to recognize the inner real emotional state of the participant [23] and is thereby able to see if the participant with a 'poker face' is actually for example sad. Furthermore, there are EEG systems that are inexpensive, portable, non-invasive, and easy to use [16], [24]. In addition, EEG can deliver a relatively high resolution which makes it useful to measure emotions [16]. Therefore, EEG systems are able to give a good and objective emotional observation.

Unfortunately, there are also some challenges while working with EEG. Understanding EEG measurements is not easy. The inspection of the brain signals requires practice and expertise [24]. Furthermore, inaccuracies could occur by artifacts. According to Kim & Andre [25], noise due to misplaced electrodes or not fully functional wires is one of the biggest artifacts when conducting EEG measurements. Other artifacts that could occur during EEG measurements are motion artifacts and muscle activity artifacts [26]. Bidgoly et al. [22] argue that wet electrodes, in contradiction to dry electrodes, are harder to attach, but also less sensitive to the motion and muscle artifacts. To conclude, the challenges of working with EEG should be taken into account and solutions should be explored further when own measurements are done.

2.3.2 EEG systems

An EEG system is able to detect brain activity. There are a lot of differences between different EEG systems. One of those differences is the way electrodes are placed on the human scalp, which is explained in the following paragraph.

Several approaches of placing the electrodes of EEG on a human scalp when measuring neural activity have been proposed. The first option is a standardized and international system; the 10-20 [23], [22]. Suhaimi et al. [23] and Bidgoly et al. [22] both state that these two numbers refer to the distances between the electrodes on the scull, placed at respectively 10% and 20% of the total longitude and latitude (See *Figure 6).* The second option is to expand the 10-20 system up to a higher amount of electrodes, to a maximum of 256 electrodes. Abdulkader et al. [16] argue that this is done to increase the resolution and the signal localization. Additionally, research done by Suhaimi et al. [23] points out that lower performance EEG

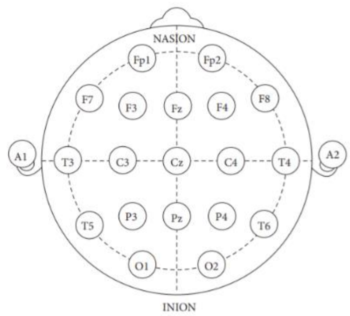

Figure 6: The 10-20 electrode EEG method [23]

with more electrodes could outperform a medical-grade EEG system with lesser electrodes. Therefore the amount of electrodes is connected to the performance and accuracy of the EEG measurements [23]. This is important information to know for this research because it can influence the choice between different EEG systems.

Next to placing electrodes on the scalp manually, there are also some other ways of detecting brainwaves with EEG. One of those methods is by doing an in-ear recording via a device that fits perfectly in the ear, like a music earpiece. These systems offer advantages like fixed electrode positions, user comfort, and ease of use [27]. This method has wireless data transmission via Bluetooth [27]. Unfortunately, this sensor is not available at the University of Twente. EEG systems that are available at the University of Twente are the Emotiv EPOC and the Muse headband, which are further explained in the following paragraphs.

The Emotiv EPOC is a cost-effective mobile EEG device with 16 sensors, which means that these sensors are able to measure the user's brainwaves in 16 different places (See *Figure 7)* [28]. These places all have their own name consisting of a letter (sometimes two letters) and a number, which can be seen in *Figure 8*. The electrodes of the Emotiv EPOC need to be wet to measure at better accuracy. After the electrodes are made wet, the headset is easily put on the user's head and thereby only needs, on average, five minutes setup time [28].

Figure 7: The Emotiv headset [28]

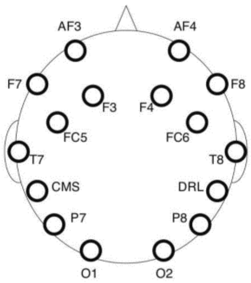

Figure 8: The Emotiv headset electrode names [28]

The Emotiv is able to transport its data via Bluetooth [28]. The output data can be seen on the Emotiv Pro app on a laptop, which displays raw data that is obtained by the electrodes. The data can be seen individually, divided into different frequency bands, or as performance metrics (engagement level, focus, excitement, and stress). The output of raw individual data can be seen in *Figure 9.*

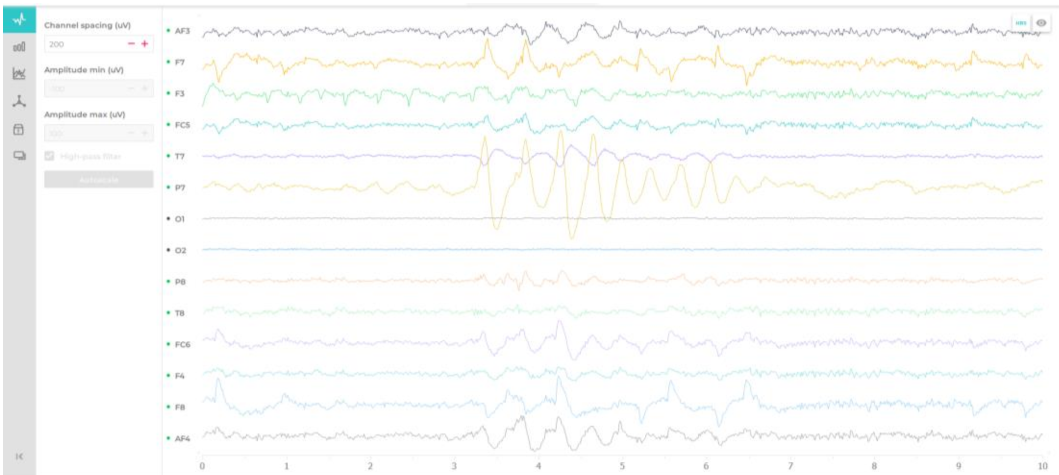

Figure 9: Raw data of all electrode from the Emotiv displayed on the Emotiv app [28]

The next EEG headset is the Muse headband. The Muse is a multi-feedback EEG device built to support meditation [29]. The Muse headband transforms brain signals into real-time feedback. This feedback can be seen on the Muse app that can be downloaded on a smartphone. Real-time feedback is possible because the data that is obtained can be directly streamed via Bluetooth to other devices. The Muse has seven sensors in total; two on the forehead, two behind the ears, and three reference sensors [29]. According to Krigolson et al. [30] these sensors on the forehead and behind the ear are analogous to the electrodes located at AF7, AF8, TP9, and TP10. The headband is easily put on the head and the electrodes do not need to be wet [29].

Figure 10 displays the first Muse headband. However, a newer version is already available; the Muse 2. The Muse 2 looks a lot like the first Muse headband but has extra sensors and features. The new properties are able to provide more real-time feedback to the user. For example, body movement, heart rate, and breath [29].

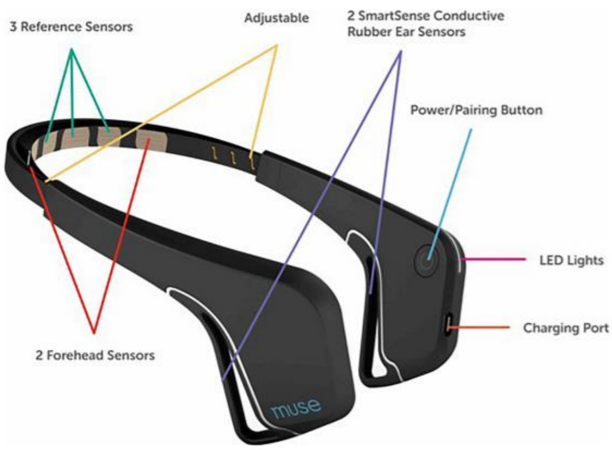

Figure 10: The MUSE headband with specifications [30]

2.3.2.1 Comparison of Emotiv EPOC and Muse headband

To be able to answer the (sub) research questions, it is important to compare the features of the Emotiv EPOC and the Muse headband, which is done in this section. The first advantage of both the Emotiv EPOC and the Muse headset is that they have wireless data transmission, which makes the devices flexible and portable [23].

The Emotiv and the Muse are both able to measure brainwaves and classify emotions afterward. However, there are some significant differences between the two systems. First of all, the Emotiv has 16 sensors that measure brain activity [28]. The Muse headband only has seven [29]. Since the accuracy of the measured brain activity is linearly connected to the number of sensors [23], the Emotiv has higher accuracy.

Another important factor is the ease of usage. The sensors of the Emotiv are very sensitive [28]. This means that it requires precision to correctly set up the Emotiv, especially if the participant has longer or thicker hair. Additionally, the electrodes of the Emotiv must be made wet before usage [28]. This increases the ability to detect brain activity, however, it is not very practical inside a museum. The Muse, on the other hand, is very easy to set up and the sensor electrodes do not need to be wet, which could make the Muse more practical inside a museum.

The next factor that may differ between the Muse and the Emotiv is the number of artifacts. This may differ because the two systems have a different number of sensors and a different way of placing electrodes on the head. Exact figures about this are not given in the literature articles, which makes it harder to compare the two. Luckily, as stated in the previous section, computer algorithms and filters are able to filter artifacts from the signal. However, if these filters are enough to also filter the movement artifacts when walking through a museum, still need to be explored. To conclude, to be able to make concrete statements about this factor, testing needs to be done.

The last factor is the connection with a computer. Both the Muse and the Emotiv are wireless and transfer data via Bluetooth. The Emotiv can be easily connected with the Emotiv Pro app on a laptop, where the acquired brainwaves can be visualised and the data can be saved and shared. The Muse is a little more difficult to connect. A separate app called BlueMuse [31] should be downloaded in order to extract the raw data. This app does not display the collected brainwaves but is able to send the data towards a MATLAB or Python script which can display the brainwaves.

2.4 Emotion recognition

Emotions play an important role in communication for human beings in daily life. Specifically, emotions affect decision-making and human interaction [23]. Additionally, recognizing and managing emotions is one of the most important skills one can have [23]. For human beings, recognizing emotions can be done with little or no effort. Nonetheless, developing a computer having this same skill is rather difficult [32]. However, with the growing interest in interaction technology between humans and computers and the quick increase in the use of smart technologies, there is a great need for emotion recognition software according to Zhang et al. [33]. This specific software is most useful in particular sectors such as; robotics, marketing, education, health care, and entertainment [32]. When machines are integrated with emotion recognition software and are being used in society, productivity and experience could be improved and the cost of expenditure will be reduced in many ways [23]. For this research, it interesting to explore emotion recognition software as it could help improve the experience and engagement inside a museum. Thus, methods should be explored to develop emotion recognition software.

Therefore, the purpose of the following sections is to review EEG-based emotion recognition methods. The first section is relatively short and contains different emotion classification models. The second and largest section of this chapter focuses on the EEG emotion recognition methods. A broad variety of EEG methods is presented and explained. The third section of this chapter includes some extra information about the Emotiv and Muse headset connected with emotion recognition methods. This section is included because these specific devices are available at the University of Twente.

2.4.1 Emotion classification models

This section contains the explanation of two main emotion classification models. These models are important for this research because they are the basis of the emotion classification process and thereby decide how and when emotions fall in a certain category. There are two main emotion classification models; the basic emotion-based model and the dimensional-based model.

Firstly, the basic emotion-based model has multiple versions. According to Ekman's model, there are six basic emotions and other emotions are reactions or byproducts from the basic emotions. These basic emotions are happiness, sadness, anger, fear, surprise, and disgust [23], [33], [34]. The second version of the basic emotion-based model is explained by Dzedzickis et al. [32]. They present ten basic emotions; anger, anticipation, disgust, fear, happiness, joy, love, sadness, surprise, and trust. With additionally 56 secondary emotions, that are less intense versions of the 10 basic emotions. Although those two basic emotions models do not completely agree on the basic emotions, they share the principle of several main emotions and other secondary emotions. However, according to Kim & Andre [25], there is a problem with this basic emotion-based model. They argue that humans can have difficulty expressing emotions in words and that the labels can be too restrictive and culturally dependent. Luckily, these limitations do not occur in the second emotion classification model based on dimensions.

The second emotion classify model classifies emotions dimensional based, which means it is based on positions on a 2-D spatial model [23], [20], [25]. On the vertical axis, the level of arousal will be measured, which represents the degree of excitement. This should be measured in the prefrontal cortex [35]. On the horizontal axis, the level of valence will be measured, which reflects a scale from unpleasant to pleasant (or positive and negative), as can be seen in *Figure 11*. To conclude, the two classification models are both able to classify all emotions. Nonetheless, the dimensional-based model could be interpreted as more useful, because it may not have the limitations of being too restrictive or cultural dependent [25].

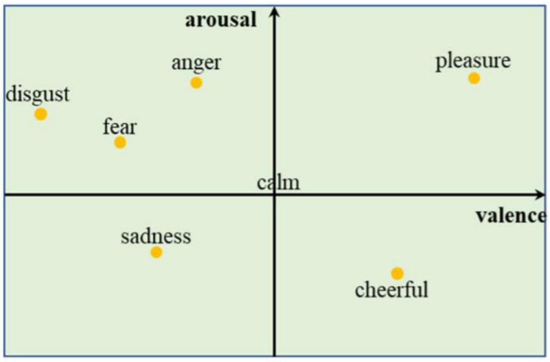

Figure 11: Basic emotions on the dimensional model [20]

2.4.2 EEG emotion recognition methods

Emotion recognition can be divided into two categories; recognition based on non-physiological signals and recognition based on physiological signals [21]. Non-physiological signals are for example voice tone, body language, and facial expressions. Physiological signals are for example brainwaves. This means that emotions are not only visible from the outside, but also neural activity can reflect emotions. A lot of studies in the neurophysiological field have reported that there is a strong correlation between the measurements of electroencephalogram (EEG) and emotions [23]. In this section, EEG emotion recognition methods are explained.

The EEG emotion recognition process can start after the brainwave measurements are done. Classic EEG emotion recognition methods consists out of four steps; pre-processing, feature extraction, feature selection and classification [3], [25], [36]. An overview of these steps can be found in *Figure 12.* The pre-processing is displayed as the first part of the feature extraction and are thereby together in a group. Additionally, the last two steps (Feature selection and classification) are also displayed in the same group. The reason behind this is explained in the coming paragraphs.

The first step is pre-processing, which focuses mostly on artifact removal. This can be done in two ways: filtering and regression or separation/decomposing [26]. Pre-processing with filtering is supported by Nakisa et al. [36]; they use a band-pass *Butterworth* filter, to eliminate different emotion-related frequency bands. This same filter is used by Konston et al. [11] to remove DC shifts. Furthermore, Konston et al. [11] have used a correlation method to identify the bad performing channels.

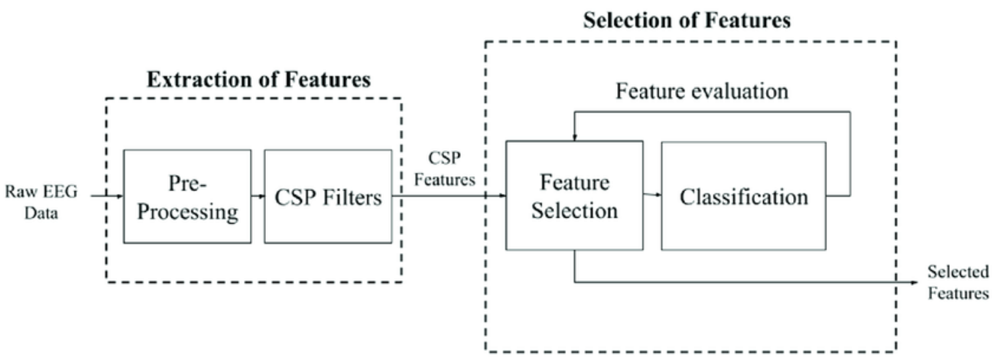

Figure 12: Classic emotion recognition method steps: [3]

The second step in emotion recognition is feature extraction, which consists out of three domains; time domain, frequency domain, and the time-frequency domain. The goal of the time domain feature extraction is to extract statistical parameters of the EEG signals as EEG features [20]. There are multiple statistical methods to extract those features; mean, standard deviation, first-order difference mean and second-order difference mean [20]. Moreover, Nakisa et al. [36] also add normalized first difference and normalized second difference to the statistical methods and argue that all the methods together easily classify basic emotions like joy, fear, and sadness. The second domain is the frequency domain. Frequencies and amplitude of EEG signals can provide clues about the physical or mental state of the person [22]. Different frequency (band) ranges reflect different emotional states. In *Figure 13* these emotional states with their link to frequency ranges can be found.

Brainwave	Frequency Range	Mental Condition
Delta	0–4 Hz	State of deep sleep, when there is no focus, the person is totally absent, unconscious.
Theta	4–8 Hz	Deep relaxation, internal focus, meditation, intuition access to unconscious material such as imaging, fantasy, dreaming.
Low Alpha	8–10 Hz	Wakeful relaxation, consciousness, awareness without attention or concentration, good mood, calmness.
High Alpha	10–12 Hz	Increased self-awareness and focus, learning of new information.
Low Beta	12–18 Hz	Active thinking, active attention, focus towards problem solving, judgment and decision making.
High Beta	18–30 Hz	Engagement in mental activity, also alertness and agitation.
Low Gamma	30–50 Hz	Cognitive processing, senses, intelligence, compassion, self-control.
High Gamma	50–70 Hz	Cognitive tasks: memory, hearing, reading and speaking.

Figure 13: Emotional states linked to their frequency ranges [12].

According to Liu and Fu [20], the frequency domain reflects human emotions better than the time domain because when a human emotional state changes, this is directly visible in the changes in amplitude and power of the frequencies. Furthermore, Nakisa et al. [36] also agree with the higher effectiveness of the frequency domain instead of the time domain. The last domain is the time-frequency domain. This domain captures both, nonstationary and time-varying signals, which can add valuable additional information [36]. According to Islam et al. [26] the time-frequency domain is popular because it can capture any changes in frequency values, due to for example artifacts, in any window of time. Additionally, there are extra tools that can help find the right balance between the time and frequency resolution, for example, Liu and Fu [20] used the Wavelet transform for this. Overall, if a domain should be chosen, the time-frequency domain includes basic functions of both the other domains and is thereby the most useful domain [26], [36].

The last two steps of emotion recognition are feature selection and classification. Many methods combine these two last steps, only Nakisa et al. [36] clearly distinguish the two steps. Nakisa et al. [36] use an Evolutionary Computation algorithm to select the most relevant features from the EEG signal, before going to the classification of emotions. Eventually, this method delivers very promising results. However, this method does require the two separate steps, where the Bayes classifier, a weighted-log-posterior function, can do these steps simultaneously [37]. This method can reach an accuracy level of 70.9% [37]. Another classification method is the Support Vector Machine (SVM). According to Bidgoly et al. [22] this method uses a hyper-plane to separate the features into different binary classes and can be used in the time and frequency domain. The SVM can be trained for better emotion recognition results in terms of accuracy rate [20]. Lastly, the Hidden Markov Model (HMM) can be used for signals in the time-frequency domain. This model can be defined as a set of hidden states with probabilities from state to state [22]. To conclude, the best fit for feature selection and classification depends on the domain (time, frequency, or time-frequency domain) of the feature extraction.

Lastly, Nam et al. [3] have made a practical overview of emotion recognition methods. As can be seen, the four steps mentioned above are put into the middle part of the overview; Signal processing. Additionally, Nam et al. [3] also have inserted signal acquisition before signal processing and feedback after signal processing. This can be seen in *Figure 14.*

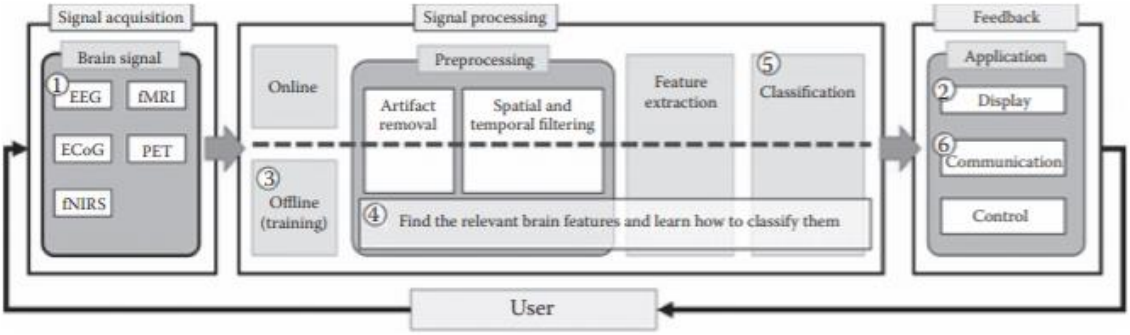

Figure 14: Brain-Computer Interfaces overview and order of method [3]

2.4.2.1 Emotion recognition methods for Emotiv EPOC and Muse headband

The four steps of EEG emotion recognition are also used in applications with the Emotiv EPOC and the Muse headband. However, for this research, it is important to know which specific steps can be taken to recognize and classify emotions measured by the Emotiv EPOC or the Muse. Therefore, several types of research are explained below.

Firstly, Ramirez & Vamvakousis [35] have used the Emotiv EPOC device for emotion detection. They have used the alpha and beta bands for research on the arousal and valence scale. The first step [35] Ramirez & Vamvakousis take is applying a bandpass filter to extract the alpha and beta bands, which is done by Fast Fourier Transform (FFT) provided by the OpenVibe software. The beta/alpha ratio is an indicator of the arousal state of a person. This is because beta waves are associated with an excited emotional state and alpha waves will be more dominant in a relaxed state. To have an indicator for the valence level, Ramirez & Vamvakousis have used a comparison of the activation levels of the two cortical hemispheres [35]. The left frontal cortical hemisphere is an indicator of negative emotion and the right frontal hemisphere is an indicator of positive emotions [35].

The second step is detecting the emotional state of a person. Ramirez & Vamvakousis [35] used an approach of training and evaluating two classifiers; Linear Discriminant Analysis (LDA) and Support Vector Machines (SVM). Both these classifiers are machine learning techniques. LDA tries to express one dependent variable as a linear combination of other features. The variable is in this case the emotional state. On the other hand, SVM projects the input data onto a higher dimensional feature space [35]. The iterative learning process of SVM can create maximal margins between the emotional states, which is a big advantage of using SVM. In the conclusion Ramirez & Vamvakousis state that the Emotiv EPOC device enough data obtains so that the two classifiers are capable of distinguishing the emotional states of humans [35].

The second research article, written by Tomas Matlovic [38], uses almost the same approach as Ramirez & Vamvakousis [35]. However, to divide the alpha and beta frequency bands, Matlovic used the Discrete Wavelet Transform (DWT) instead of the Fast Fourier Transform. The outcome is equivalent. Furthermore, Matlovic used more features than only the alpha and beta waves to support the SVM, namely the extreme and mean values of the raw EEG data. This is done to receive a higher accuracy. However, this improved his results only by 3 % thus was not as effective as hoped [35].

The third research is done by Pham & Tran [39]. They used, just like Ramirez & Vamvakousis, the Fast Fourier Transform to find the average signal of the frequency bands. After this, Pham & Tran used four algorithms to build a model for emotions; SVM, kNN, Naïve Bayes, and AdaBoost.M1. In the result can be seen that AdaBoost.M1 has the highest accuracy rate of 92.8% and SVM with 89.25% in second place [39]. In the conclusion, they state that the Emotiv EPOC is good for implementing emotion recognition applications in for example the entertainment industry [39].

Next to the Emotiv, also the Muse headband is used in several types of research as the main data input. Firstly, Laureanti et al. [40] have researched the emotional state of people during stimuli exposure measured with the Muse headband and the Shimmer GSR + device. The Shimmer device measures the skin conductance and the heart rate of the user. The data that is obtained via the Muse headband will first be pre-processed. For this, Laureanti et al. [40] have used Matlab and the EEGLab toolbox. The next step is to classify the obtained data into emotions. For this, they used machine learning techniques to divide the data into six groups; arousal and valence with both groups of low, medium, and high values. In the end, Laureanti et al. [40] conclude that the level of arousal can be obtained with more accuracy than the level of valence [40].

Secondly, Simar et al. [41] also used the Muse headband and real-time data processing in their application. They have used the input Muse data, which reflects the emotional state of a person, as a controller for a small robot. To achieve real-time data they used the Lab Streaming Layer system [41]. This system allows researchers to synchronize streaming data across different devices [42]. In their research, Simar et al. [41] showed that even with consumer-grade dry EEG caps (Muse) they can control a robot in real time.

2.5 Interviews

As part of the state of the art research, three types of interviews are held; interviews with 'museum experts', interviews with artists, and interviews with museum visitors. The 'museum expert interviews are held to collect more inside knowledge about museums themselves. A museum expert is for example the head of a museum or the curator. The interview with artists are done to gain more information about the artists view towards art and museums. The other interviews are done with people who visit museums regularly. These are people within my household due to Co-Vid 19 measurements.

All the interviews are semi-structured, which means that several questions are prepared, but also new questions are asked if the conversation leads to it. Also, if the interviewee tells something specifically interesting, more questions about this topic are asked. The prepared questions for the expert interviews can be found in *Appendix A* and the questions for visitor interviews can be found in *Appendix B*. Before the interviews, all interviewees are asked to read the information brochure and sign the consent form. These documents can be found in *Appendix C.*

Two expert interviews are held with employees of the MuseumFabriek and Concordia. Another expert interview is held with a philosopher professor of art, technology, and interaction of the University of Twente. The artist interviews are done with artists with paintings hanging in various museums in the Netherlands. Summaries with the main findings of these interviews can be found in the following sections. The names of all the interviewees are made anonymously due to privacy regulations.

2.5.1 The MuseumFabriek

29-03-2021

The interviewee works for the MuseumFabriek in Enschede. The MuseumFabriek is a museum with lots of different exhibitions. The main focus of the museum is on nature, Twents- culture, and textile history [43]. The MusuemFabriek has between 200.000 and 300.00 exhibit items which most of which are gifts from the original owner to the museum [43]. The interviewee is the head of the collections of the MuseumFabriek. Additionally, he is the project leader of most of the exhibitions within the museum, which means that he is responsible for which items will be displayed and in which way that is done best. He tries to give visitors the best experience possible and is constantly busy improving the experience.

The visitors of the MuseumFabriek can be divided into four groups; families, elderly, experts, and young professionals. At MuseumFabriek, the family group is by far the largest with 60% of the total visitors. The interviewee stated that there are two kinds of information that a museum wants to tell a visitor; the story of the whole exhibition and the individual information about a specific item. One of the challenges of the museum is to provide interesting information for all different groups. A lot of specific information can be interesting for the experts but could be too much for children who will lose interest quickly. A museum should try and find the right balance in what kind and how much information is given to the visitors.

The MuseumFabriek already has experience with the VidiNexus screen. The interactive screen is used at the entrance and within an exhibition. However, it did not work out as expected. The screen had too many options in which users quickly lost interest. Also, the application was for most users too hard to understand and too vague to really receive the specific information. The interviewee was convinced that the screen could improve a museum visit if the application is user-friendly and thereby easily accessible.

Another important aspect the interviewee pointed out was that implementing new technologies into museums is not very easy. The MusuemFabriek tested applications with VR glasses. A problem that they immediately came across was that the installations were not volunteer-proof. If a part of the application stopped working, the volunteers who work at the museum (and are mostly above 50 years old), did not have the knowledge to fix it. The difficult technology behind the VR glasses made sure that there almost always should be a professional available to fix problems if they occur. Another problem that occurred when testing VR glasses inside the exhibitions is that children knew how they could change certain aspects of the glasses. They were able to change the settings to, for example, a rollercoaster, instead of the exhibition settings. The new technology should also be protected against thieves. The mobile phones inside the VR glasses are easily removed from the glasses and could be taken away. The last aspect the interviewee pointed out was that technologies, like VR glasses, need power. The mobile phone needs to be charged after approximately 2 hours, which requires manpower and organizing skills.

2.5.2 Concordia

31-03-2021

The second interview is done with the curator of Concordia. Concordia is an art and movie theater located in the city center of Enschede. The interviewee works for the department of visual arts. She is responsible for the expositions that are shown and the artists who participate. This is done a couple of years ahead. In this way, the artist has time to finish the art-works and prepare for the exhibition.

The target groups of Concordia are families, elderly/city people, and art-lovers. Concordia has four different exhibition rooms. The room at the entrance of the building is displaying art for families and people from the city. The second and third rooms are displaying more daring exhibitions, to attract art-lovers. The room at the top of the building displays art from artists who are recently graduated from art schools in The Netherlands or Germany.

The information that every target group wants to receive in a museum differs a lot. Concordia uses multiple methods to spread information about the exhibitions. Firstly, instead of hanging small signs next to an artwork with information about the artist and the art itself, handouts with this same information are given at the entrance of the museum. This is done to distract visitors as little as possible from the art itself. The information in the handouts differs per target group. For families and people who are not familiar with the art, the handout is filled with information about the way of looking at art. It provides general tips on how to look at art. Additionally, the handout gives information about what the artist wanted to achieve with the art and how this can be seen in the artwork. On contrary, the handout for art-lovers is filled with background and more specific information about the artist, art style, and artwork. Sometimes even art history is included.

The second method Concordia uses to spread information is small screens inside the exhibitions. The screens are used to take visitors through the process of the artist. The screens display a short movie, around three to four minutes. Concordia does not want the screens to get too big. This because it would take a lot of attention at the expense of the real artworks.

The interviewee was very enthusiastic about EEG and emotional feedback. Concordia does not collect any feedback about the visitors' experience. The interviewee believes that a feedback system that displays what art-works evoke which emotions and the magnitude of them, could be very valuable for a museum. By knowing that information, a museum can make better exhibitions.

The main difference between Concordia and the MuseumFabriek is that Concordia lays much more focus on the feeling and experience of art. Concordia wants to teach visitors how to look at art and how an art experience is different for everyone. The MuseumFabriek has way more focus on scientific information transfer to the visitors.

2.5.3 Philosopher of science; University of Twente

15-04-2021

The third interview was done with a philosopher of science at the University of Twente. She is specialized in the connections between ethics, art, and technology and therefore very interesting for this research. She has a very specific view of how the experience inside a museum can be improved. She stated that the experience is all about the way people look at art.

According to the interviewee, people have very high expectations when visiting a museum and watching art. People expect to feel something (for example an emotion) immediately when they look at art. However, this is rarely the case and is thereby very rare (and beautiful) if it does happen. But because people have these high expectations that may not be met, the experience of the whole museum visit will downgrade. Another aspect that influences the museum experience according to the interviewee is the gap between feeling and thinking. Or in philosophy terms; ratio and emotion. For a lot of people, these two aspects bother each other, while they should support each other.

The interviewee states the way people look at art is one of the main elements that determine the experience inside a museum. People should let go of the thought that they need to feel emotions immediately when looking at an artwork. She remembers us that looking at itself is a verb and requires discipline. Through looking, a connection with the artwork can be formed and people may experience emotions. However, as state above, experiencing real emotions at artworks is rare. According to the interviewee, the emotions people feel when looking at art is a result of the connection with the artwork.

To get this connection between the artwork and yourself an active way of looking is required. She states that this can be done through asking questions and taking a long time for each artwork. People should stand before an artwork and start by answering questions like; What is the genre? What does the art display? Where is it? What is the ambiance of the art? After answered these kinds of questions, the questions could go towards more art-technical aspects such as; What is the art style? What is the composition? What do the lines display? What is the use of color? After this, different artworks in the same genre can actively be compared to each other. In this way, a connection with the artwork may be achieved.

The interviewee explains that this way of looking at art, by answering questions, is closely related to meditation. At meditation, it is important that you have full attention and put your emotions aside. You can notice things, but feelings are not the main focus. This is the same when looking at art. She stated that technology that stimulates people to pay full attention to an artwork, could have a very positive effect on the museum experience of visitors.

Furthermore, she explains that the connection between the visitor and the artwork is also very important outside the museum. For people in general, it is important to make connections. Think of for example love or nature connections. The museum experience and the connections people make with art, offer enrichment of the experience of daily life. The interviewee states that art and a museum experience should provide more than only a specific feeling at the moment. It is also about what feelings people remember and how the connections can be reflected in their daily life. A museum should offer an experience that also after visit allows to see beauty in for example the environment.

Additionally, she told us that art is something that needs to be experienced alone. In that way, the visitor can make an honest connection with the artwork. If there is looked and talked about a specific artwork within a group, aspects like peer pressure have a great impact on the experience and connection towards the artwork. People are afraid to say their opinion or take other opinions as truth. The connection a person has with the artwork is very personal.

This interview is very interesting for this research. That is because the interviewee has a very specific way of looking at the experiences inside a museum. Her view is very different than the literature found until now. The fact that actively looking and inspecting an artwork improves the experience inside, but also after the visit, is valuable information. The specific way of looking and asking yourself questions about the artwork may be supported by technology to improve the experience even more.

2.5.4 Artist (1)

19-04-2021

The fourth interview is done with a Dutch artist. His art is displayed in several expositions inside museums throughout the Netherlands. He is a traditional artist who creates drawings and paintings. This interview is done to gain information about the subject from an artist's opinion.

First, there was talked about experiences inside a museum. His opinion of improving the experience inside a museum has everything to do with freedom. He states that museums should stimulate visitors to form their own opinions and feelings for each artwork. Love for art only comes if you are able and free to form your own opinion. He states that love for art grows and therefore takes effort and time. The connection that can be formed with art, is different for everyone and therefore should not be explained by the museum too much. He stated that a lot of information inside museums is already pointed in a certain direction, which may form how visitors think. In conclusion, visitors need to be free to form their own opinions to achieve the best experience inside a museum.

Additionally, the artist is of opinion that the museum looks down on people. The information that is given is, according to him, too simplistic and implicates that visitors are dumb. He agrees with the statement that personalized information may improve the experience inside a museum. This information could be based on for example preferences or intelligence level.

Furthermore, he explains that the experience of art is very dependent on the environment where the art is displayed. A large and open room gives art a completely different feeling, in comparison with a dark, packed, and small room. The artist states that it may even be best if art is displayed in nature. In that way, the connection visitors have with art may improve. Changing the environment is not in the scope of this research, however, this view does give an insight into other aspects (next to information supply) that have an influence on the experience of art inside museums.

Lastly, the artist is of opinion that museums are behind on using new technologies. He states that museums are old-fashioned and do not move forward together with the rest of the world. In his opinion, technology can add great value to the experiences of visitors inside a museum.

2.5.5 Artist (2)

04-05-2021

This interview was done with an artist from Amsterdam. She is a multidisciplinary artist who makes paintings, drawings, bronze artworks, and glass artworks. This interview was done to gain more information on museum and art experiences from an artist's perspective. Additionally, opinions and facts about other interviews were discussed to look for common ground and confirmation.

This artist is very passionate about colours and materials. She wrote several books about the basic colours and materials used in different eras inside artworks. Therefore, her opinion is that museums do not provide enough information about different art techniques. The artist states that the connection with art can be improved if the museum provides more information about the art techniques. So, more information about the different colours and materials used in the artwork.

Additionally, there are other aspects of information supply inside museums that can be improved according to the artist. She states is that the general information supply inside a museum is too focused on popularity. Most of the information is addressed to people who have little knowledge about art. According to the artist, the given information is altered and simplified too much, just to fit into popularity trends at that moment. This decreases the experience visitors can have inside a museum. She states that museums look down on people and do not see the full potential of the visitors. According to her, the information flow should challenge visitors to learn and develop during their visit. This is in accordance with the statements of the previously interviewed artist (1).

When continuing about the information supply subject, she states that personalized information can be very valuable inside a museum. However, to provide personal data, the artist states that a very large database is needed with extensive information about a different aspect of the artwork (for example colours and materials). She already did some research about databases when she was writing her books about colour and materials inside artworks. However, she was disappointed in the amount of information databases have. This makes it, in her opinion, very difficult to provide personal information to visitors.

The last aspect that was talked about during the interview was the connection visitors may have with artworks. The artist agrees with the philosopher of science (previous interview) about the idea that the connection that can be formed with art is very important for the experience of the museum. However, the artist does not agree with the way the philosopher tries to achieve this connection. The artist, in contrast to the philosopher, does believe that feelings and emotions come quickly when looking at art. Furthermore, she believes that these feelings that come naturally are the most important. Lastly, she states that factual thinking about artworks can disrupt the instant feelings about an artwork. This is directly the opposite opinion of that of the philosopher, which makes it difficult to conclude anything from it.

2.5.6 Museum visitors

The interviews with museum visitors are done with housemates, friends, and family, who frequently visit a museum. The number of interviews that are done is seven, which may not be enough to make direct conclusions. However, the information gathered by these interviews can be used as an inspiration for the final interactive system.

The goal of these interviews was to get to know the interviewee's experiences inside a museum. The questions that were used can be found in *Appendix B*. However, when conducting these interviews, it was hard to stick to these questions. Eventually, the interview became more of a conversation about experiences, engagement, and feelings within museums. Nonetheless, valuable information came up.

The interviewees can be divided into two age groups; 18-25 and 50-60. There were no big differences between the two age groups, however, museum experiences did differ a lot from person to person. Overall, almost all the interviewees would like to have more interaction inside a museum. Other suggestions were to make a museum visit more personal. Interviewees stated that they would have better experiences inside the museum if they were able to connect on a personal level with the artworks. For example, something that brings back memories from their own lives. One of the interviewees would like to be 'forced' to look longer at certain works of art. The interviewee feels like the art is better understood and new insights would come up.

Around half of the interviewees like to receive information and extra insights about the artworks via an audio tour. The other half experiences an audio tour as rather isolated, they would like to come to new insights and information by talking to other visitors. Furthermore, one interviewee pointed out that this feeling is also depended on the mood of the day, and could therefore also differ from day to day. Another way of receiving information that is positively experienced by the interviewees is interactive screens. Interviewees stated that they would like to have the option to choose between information that they receive. Interactive screens are a good solution to that. However, one of the interviewees stated that she feels pressured when looking at the interactive screen too long because others also want to use the screen. Therefore, she is not completely comfortable with this system. Although this was only mentioned by one of the interviewees, it is an important aspect to take into consideration for this research.

All the interviewees stated that they are okay with their brain activity being measured, as long as the data is used anonymously, and preferably deleted after the visit. Interviewees told that they would feel less comfortable if the measured brain wave data is visible to everyone around them. This is important information for this research because it sets some limits to the possibilities of using the brain activity of visitors.

One of the interviewees told a very interesting story. The interviewee graduated from art school a couple of years ago. She told me that during her time at art school, she used museums as a source of inspiration and education. At that time, when she looked at art, she could recognize the art techniques learned at school inside the art that was displayed in the museum. She was able to look at the artworks in many different ways and thereby she felt that her experience and engagement of the museum visit were very high. She also used these same techniques to find patterns and rhythms outside the museum in a 'normal' outside environment.

Nowadays, she does not know all these techniques anymore, which for her makes museum visits less appealing. She would love to receive feedback from the museum about this topic or be remembered about the different ways of looking at art. This story is of special interest to this research because it aligns with the main goal of Concordia; educate visitors to look at art in different ways to improve the experience in museums. Additionally, the fact this interviewee also used her looking techniques outside of a museum environment, connect this story also with the philosopher of science (*Section 2.5.3)*

2.6 Conclusion

The state of the art research is divided into multiple aspects of the total research. This conclusion section describes the main findings which answer the sub-research questions of the first two topics; Museum & Art and BCI.

As the goal of this research is to improve the experience and engagement of visitors inside Dutch museums, it is important to know how museums and art are experienced in the first place. Despite the recommendations and disclaimers given by Leder and al. [8] the model of aesthetic experience (See *Section 2.1.1)* could be of great importance for this research. This because it provides a clear overview of the different aspects that have a role in the way visitors experience art.

Another approach to improving the user experience inside museums is done at the art museum Concordia (*Section 2.5.2*). The goal of Concordia is to teach visitors different ways they can look at art. In that way, Concordia wants to improve the experience of visitors in their museum. Additionally, the third interviewee (*Section 2.5.3*, Philosopher of science) stated different ways in which visitors can learn to look at art. This interviewee also agrees that when visitors take their time at each artwork and know which aspects to concentrate on, the experience inside a museum improves a lot. This is important information for this research as it gives a concrete suggestion of how a museum experience can be improved.

Furthermore, the research of Brieber et al. [9] and Leder et al. [8] are important for this research because they state that the environment in which art is displayed has a huge impact on the experience of art. In a later state of this research, multiple user tests need to be done. It is important to keep the results of Brieber et al. [9] and Leder et al. [8] in mind because they could influence the results of the user test. Preferably, the user tests are done inside a real museum environment. If that is not possible, the technique of Leder et al. is used.

As stated in *Section 2.1.2,* an interactive system may be able to help improve the engagement of visitors inside a museum. Also, the interviewed museum visitors were very enthusiastic about an interactive system inside museum environments. However, the difficulties stated by Campos et al. (*Section 2.1.2)* need to be kept in mind during the ideation, specification, and realisation phase of the research to achieve a better outcome of the research.

The second part of the State of the Art research focuses on the subtopic; BCI. BCI systems could be valuable for this project because these systems are able to measure brain activity and thereby give real-time personal feedback which could improve the interaction between the user and the museum. Since EEG devices can be low-cost, portable, and easy to use while keeping a sufficient accuracy [16], [24], EEG devices are used for this research.

At the University of Twente, the Emotiv EPOC and the Muse headband are accessible. In *Table 1*, the differences between the Emotiv EPOC and the Muse headband are summarized. As can be seen, the Emotiv EPOC has a lot more positive features in comparison with the Muse. Especially useful is the feature of the Emotiv EPOC to be able to display and share modified data, for example, engagement levels, excitement levels, or focus levels. However, the Muse is way easier to use for the user. This is because the Muse headband does not need wet electrodes and can be easily put on the head. This is a very important feature because it could have a great impact on the user experience inside a museum.

Even though the Emotiv EPOC is not convenient for museum use, the Emotiv EPOC is chosen as EEG device for this research. This is because unfortunately, the Muse headband available at the University of Twente is not able to connect with the computer at all. When a newer version of the Muse is available at the University and is able to connect with a computer, a switch between devices can still be made.

Table 1: The Emotiv EPOC vs. the Muse headband

	Emotiv EPOC	Muse headband
Amount of sensors	16	7
Ease of use (user)	-	++
Ease of use (researcher)	++	-
Computer connection	++	-
Raw data collection	+	-
Modified data collection	+	-

The interviewed museums (MuseumFabriek & Concordia) were both very enthusiastic about the idea of an interactive BCI system in a museum environment. However, the MusuemFabriek stated that the new technologies should stay understandable for museum employees and volunteers, as they should be able to help people who do not understand.

Also, most of the interviewed museum visitors (*Section 2.5.6)* were very enthusiastic about a BCI system inside museum environments. They are okay with their brain activity being measured, as long as the data is used anonymously and preferably deleted after a visit. This is important information for this research because it sets some limits to the possibilities of using the brain activity of visitors.

Chapter 3: Ideation

After the background research was concluded, the ideation phase started. The ideation phase focused on brainstorming and coming up with ideas to create a final concept. The ideation phase started with a short formulation of the design context and design vision. From this, the stakeholders were distracted and analyzed. The needs and interests of the stakeholders were translated into design requirements. Additionally, the background research of the previous chapter was used to guide the creative process. Then the actual brainstorming started. This chapter summarizes the brainstorming sessions and concludes with the first consolidated project ideas to be elaborated in further phases of the research.

The mandate of this design project was to come up with a design for museums that includes a VidiNexus screen and an EEG device. The chosen context for the design is art museums in The Netherlands. These museums may include artworks such as drawings, paintings, or installations. Furthermore, the design includes a VidiNexus screen and an EEG device. The design vision is to create an interactive system that improves the engagement and experience of visitors inside a museum.

3.1 Stakeholder analysis

This section states the stakeholders of this project. It is important to know the different stakeholders and their interests because it helps the design process and therefore leads to a better product for all people involved. Furthermore, by knowing and understanding the stakeholders, it becomes easier to predict the consequences and the potential difficulties. The stakeholder analysis consists of three steps. The first step is to identify all people involved; the stakeholders. The second step is to prioritise the stakeholders. The last step is to understand the key stakeholders.

The first step is to list all involved stakeholders, in this case, all people that have a stake in a regular Dutch art museum and the technology providers:

- Museum visitors
- Artists
- Curators
- The head of the museum
- Museum employees & volunteers
- Dutch government
- VidiNexus
- Company that is providing BCI systems

The second step in stakeholder analysis is to prioritise the different stakeholders. This is done to know on which stakeholder group the further research and brainstorm process should focus. This step is done with the help of an influence-interest graph, in which the stakeholders are placed, see *Figure 15*.

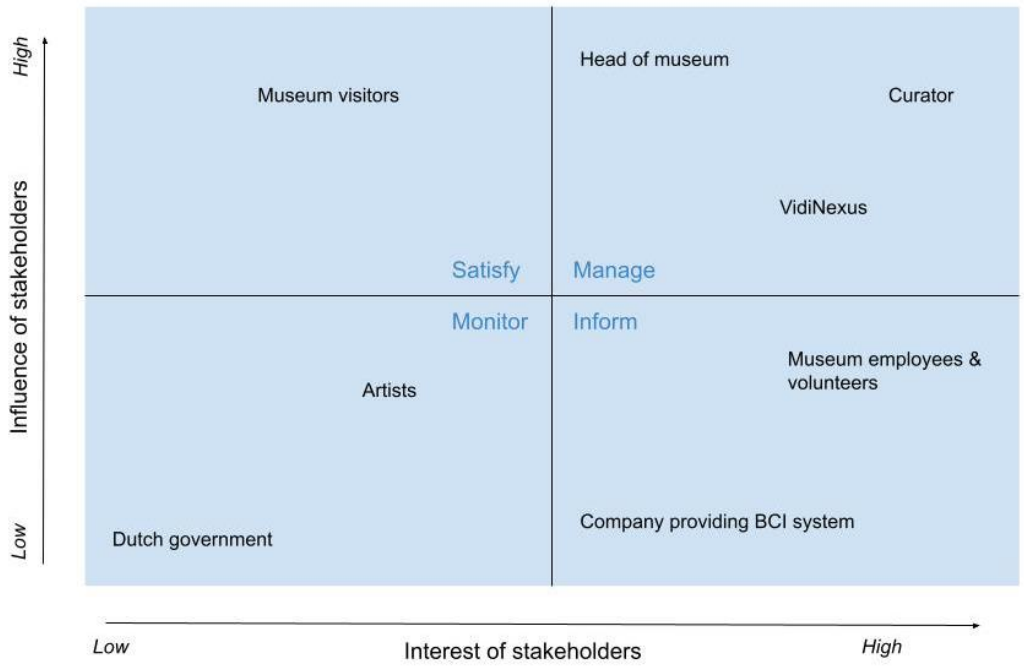

Figure 15: Stakeholder analysis

The last step in the stakeholder analysis is understanding the key stakeholders. This is important because the key stakeholders have great impact on the final design. Understanding them improves the chances of developing a successful system. The key stakeholders of this project are the museum visitors, the head of the museum, curators and VidiNexus, which can all be seen in the upper half of *Figure 15.*

Museum visitors

Firstly, the museum visitors have an interest in the system because it should improve their experience inside a museum. The interests of this stakeholder group should have a lot of influence on the final system because they are the end-users of the system. This stakeholder group is diverse and consists of lots of different people. Think of for example; art lovers, families and elderly. Ideally, the system satisfies everyone.

It is important to keep close contact with museum visitors because this group can be used to test different iterations of the system and can be asked for feedback. Furthermore, this stakeholder group could be useful during the brainstorming sessions to come to original ideas.

Museum head

The next key stakeholders are the heads of a museum. This group has a financial interest in the designed system. If visitors like the system a lot, they might come to the museum more often, or they could tell their friends who might also visit because of the positive talk. More visitors equals more money for the museum and therefore satisfies the museum head.

The interests of the heads of a museum should well be taken into account because they decide whether to invest in such a system. Therefore, it is important to keep in contact with the heads of a museum and ask for their opinion. For instance, when the brainstorming phase is over and a general idea is formed, it could be interesting to run this idea past this stakeholder. They are able to give useful feedback and recommendations to improve the system.

Curators

The next key stakeholders are curators, who also have a very high interest in this system. Because they are head of the collections inside a museum, they control the experience visitors have inside a museum. Curators are responsible for the story a museum tells and the engagement of the visitors inside. Their experience could be of great help during the design process. Furthermore, if the system is implemented inside a museum, curators may need to adjust their storyline or arrangement of artworks.

VidiNexus

VidiNexus is the last main stakeholder. VidiNexus has an interest in this system because the system uses its interactive screens, which means that the system could become an income source for VidiNexus. Furthermore, the system brings the company VidiNexus publicity and brand awareness, because visitors are able to see that the screens are made by VidiNexus.

It is important to stay in touch with the VidiNexus because they exactly know the feasibilities of the screen and could therefore help with the final stages of the project. Furthermore, VidiNexus could be used to get feedback on the system during the design process. In that way, adjustments according to their preferences can be made.

3.2 Design requirements

The design requirements are stated in groups from the perspective of the main stakeholder groups. The museum head and curators are combined into one stakeholder group, as the requirements are similar to them. At the end of this section, an overview of all requirements is given in a MoSCoW table.

Museum visitors

Most of the design requirements from a visitor's point of view have to do with the connections they feel towards artworks. As can be concluded from the background research, it is important for visitors to feel a connection with an artwork. This connection can be for example an emotion. However, according to the philosopher of art and an artist interviewed (*Section 2.5.3* & *Section 2.5.4*) this connection between visitor and art is rarely reached. Additionally, a couple of museum visitors that are interviewed state this same feeling (*Section 2.5.6*). The system could make visitors aware that feeling a connection with art is not standard. In that way, people do not feel disappointed when this connection does not immediately appear and the experience of the museum improves.

Fortunately, it is possible to provoke a connection with certain artworks. To achieve this, an active way of looking is required. This 'active way of looking' can, for example, be achieved by following the steps stated in the summary of the interview with the philosopher of science (*Section 2.5.3).* This method encourages visitors to postpone their emotions and thought to first look at the painting factually. Therefore, the system may improve the experience by making visitors look actively at artworks.

Besides that an active way of looking helps to form a connection, also looking longer at art makes it easier to form a connection. Visitors (on average) do not take enough time in front of an artwork, namely only 9 seconds (Interview , *Section 2.5.3).* A connection is rarely formed within these 9 seconds. Therefore, the designed system could make sure visitors spend a longer time at each artwork, which may improve the understanding of the artwork and thereby enhance the total experience of the museum.

Additionally, interaction helps visitors to feel connections with artworks. Moreover, as interactivity may improve the engagement and experience of a visitor [2], interactivity is one of the main requirements from a museum visitor's point of view.

The last design requirement is not focused on the connections, but on the privacy of visitors. BCI could invade visitors' privacy if the data is used for other things than the system itself. The data should only be used for the system and deleted afterward.

Museum

Also from the museum (museum head and curators) point of the view, multiple design requirements are listed. First of all, during the interviews, museum curators stated that they do not want a big screen too close to art (*Section 2.5.1 & 2.5.2*). This is because it could distract visitors from looking at the art itself. Therefore the design should be placed at a spot inside a museum where it does not distract visitors from the art. Suitable places may be the entrance or exit of the museum, an empty room between the exposition rooms, or a hallway.

Secondly, the designed system should not be too difficult to use technically. Generally, the museum employees and volunteers do not have the knowledge to fix a technological issue of the system (*Section 2.5.1*). This problem was found during the interview with the MuseumFabriek (*Section 2.5.1),* where they told about experiences with implementing new technologies inside the museum. Unfortunately, implementing those new technologies did not work out well. Therefore the system should be robust for technological errors and small problems should be easily fixable by museum employees.

Thirdly, the museum should ensure that the designed system implements new technologies, such as BCI. This is because according to the background research, museums must adapt themselves to remain relevant for visitors [4]. Lastly, the system is most useful to the museum if it is applicable for all user groups, or if not possible, to as much user groups as possible. In that way, the system can be used as much as possible and the most people benefit from the system.

VidiNexus

Lastly, design requirements from the VidiNexus view are listed. Firstly, the design should consist of a VidiNexus screen. In that way, VidiNexus is able to profit as much as possible from the designed system. Furthermore, the system would be of most use for VidiNexus if the system can be used in multiple museums. Therefore, a design requirement from the VidiNexus point of view should be flexibility and adaptability of the system.

Moscow table

The design requirements can be separated into functional and non-functional requirements. Functional requirements are about the user interaction, the features of the system, the software and the hardware. A functional requirement is for example to use the VidiNexus screen and BCI sensors. Non-functional requirements are, amongst other things, requirements about the user experience and the look of the system. This means that if the non-functional requirements change, the system is still able to function properly. The functional and non-functional requirements are stated together in *Table 2.*

Lastly, the MoSCoW method is used to set priorities to the design requirements. Within this method, the requirements are divided into four different groups; must, should, could and wont. This gives a clear overview of which requirements require the most attention during the brainstorming sessions. The results of the design requirements can be seen in *Table 2*.

Table 2: MoSCoW method for design requirements

Must	Should
- Use the VidiNexus screen - Use BCI - Be interactive - Be integrated inside a museum environment - Give feedback real-time personal feedback - Improve experience and engagement of visitors	- Be applicable for all user groups - Be able to give the visitors options according to preferences - Enhance an active way of looking - Give visitors more information about the artwork - Be usable in different museums
Could	**Wont**
- Be able to sense to which painting the visitor is looking - Make sure visitors spend a longer time at each artwork - Encourage users to postpone their emotions - Use multiple sensors	- Use technology that is too hard to understand for museum volunteers - Make the system mandatory - Violate the privacy of visitors - Make visitors uncomfortable - Alter the museum too much that it is not fun anymore without the system - Take too much time

3.3 Brainstorming

The brainstorming phase is a very important phase of this project. The design aspects, design requirements, and stakeholder analysis were used to guide the brainstorm and different brainstorming techniques were used to create concepts. For example; mind-mapping, gap filling, and reverse brainstorming. Unfortunately, it was noticed that brainstorming alone was not enough. It proved that, in this project, talking with stakeholders helped the idea generation most.

3.3.1 First concepts

During the first phase of the brainstorming process, the brainstorm was mainly focused on improving the experience by making a design that can be used during the whole visit. Different elements of the total system were explored and are listed in the table in *Appendix D*. On the basis of the elements in *Appendix D,* multiple concepts were created. Four concepts are explained shortly below.

1. **Personalised audio tour**
   This is an update of the classic audio tour that is already available inside lots of museums. In this system, the audio tour is connected to the Emotiv EPOC. If the Emotiv EPOC senses that the engagement is very low or negative, the audio tour adapts the information flow.
2. **Mindful art experience**
   This system challenges people to postpone their emotions by 'forcing' them to first look at the artwork in a factual way. This is achieved by asking the visitor questions. The techniques learned during the interview with the Philosopher of science of the University of Twente (*Section 2.5.3*) is used. In this way, visitors may feel more connected towards the artworks.
3. **AI audio system**
   An audio system uses machine learning to adapt the information flow during the museum

visit. The system learns from the Emotiv EPOC engagement levels and the walking pattern of the visitor through the museum. These factors adapt the information flow.

4. **Art engagement profile**
   In this design, the visitor wears the Emotiv EPOC during the whole visit. At the end of the visit, the visitor receives feedback via the VidiNexus screen about their visit and his/her emotions or engagement levels while looking at different artworks.

These four concepts are placed in the WOW-graph (*Figure 16*). The WOW- graph visualises the feasibility and the originality of the concepts. As can be seen in the graph, none of the concept are placed in the WOW (top right) corner. This means that none of the concepts consist of high feasibility and high originality.

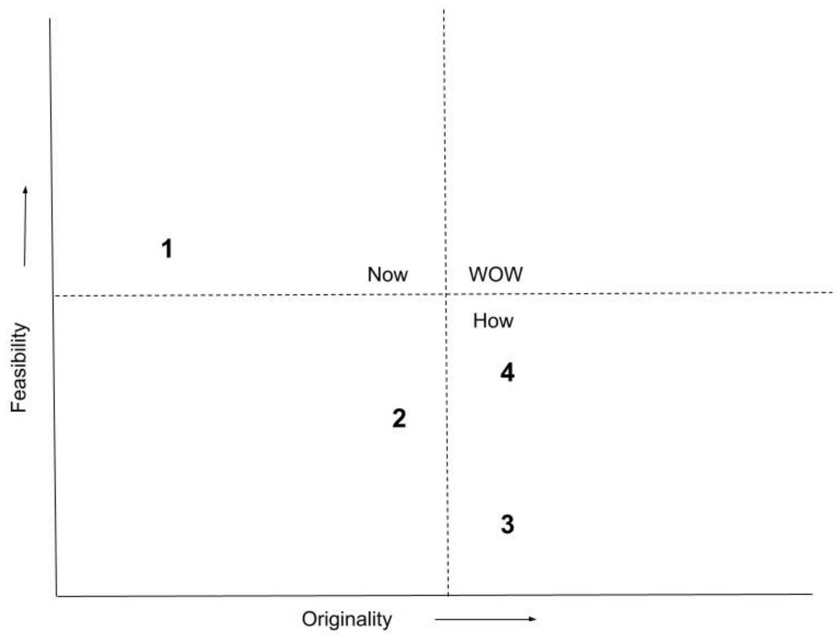

Figure 16: WOW-graph of the first four concepts

3.3.1 Technical feasibility check

When exploring the technical feasibility of these four concepts, it was found that the concepts have a lot of disadvantages.

The first disadvantage is the accuracy of the Emotiv EPOC. As found out in the background research (*Section 2.4.2*), a lot of steps need to be taken from measuring brain activity to classify emotions or engagement levels. Furthermore, it might be difficult to achieve sufficient accuracy. If the outcome of the system does not match with the feelings the visitor is consciously feeling, the visitor may not believe the system. The visitor may lose all interest in the system. Therefore, the Emotiv EPOC may not be accurate enough for this kind of application.

Furthermore, a common difficulty for these concepts is that the system does not know where the visitor is and what he is looking at. If the system changes the outcome based on Emotiv EPOC, while the user is looking at his/her phone, the data is not usable. To receive accurate data about the whereabouts of the visitor, more sensors are needed. For example, eye-tracking sensors that establish whether the visitor is really looking at art. However, this could become way too complex and is thereby out of the scope of this research.

The next disadvantage that can be found in the concepts described above is that some of them do not use the VidiNexus screen. VidiNexus is the client of the system and should therefore benefit as much as possible of the system. A system that actively uses the VidiNexus screen is of more interest for VidiNexus. Therefore, a concept needs to be created with the VidiNexus screen at a more central position.

The last disadvantage is that not all visitors want to learn about art. Designing a system that helps people how to look at art, or providing more information on an artwork, may not work for these visitors. If a visitor does not have any interest in this, immediately the whole system is not interesting for him/her anymore. Designing a system that is of interest for everyone may prove to be too difficult, however, the system could be more open to different user groups and thereby include visitors that do not want to learn about art aspects. This could increase the use and success of the system. Therefore, informing visitors about the different aspects of art should not be the main element of the system, however could still very well be used as a secondary function.

3.3.2 Continuation of the brainstorming process

Due to all the disadvantages described above, new concepts (or altered concepts) were needed. The focus was brought back to the VidiNexus screen and interactivity between the museum and the visitor, which are the main requirements of the design. During the technical feasibility check, it is found that combining these factors (interactivity and VidiNexus screen) with teaching visitors how to look at art (in a subtle way) would be ideal.

After brainstorming with these new insights, the concept of game-based learning quickly came up. Lots of ideas like quizzes, board games, chance games, and multiplayer games were thought of. This part of the brainstorming process is summarized into a mind map, which can be found in *Appendix E.* Eventually, a quiz is chosen as the best option for the game-based learning environment because a quiz can be fun, challenging and interesting for the broad user group that can be visiting a museum. If for example multiplayer game is chosen, two people are needed for the system. This would already exclude the visitors who visit alone.

A challenge in this solution lies in combining the game-based learning concept with the input of the Emotiv EPOC. As stated in the background research, BCI can be used in games in two ways. The first way is when BCI is used as 'control by affective state', which alters the task load or difficulty of the game [14]. The second way is issuing commands by brain signals. Here BCI is used to control the game itself. For example by imaging movements, event-related potentials, emotions or mental state can be used as input for the game [14]. Because the average accuracy of the Emotiv EPOC could fluctuate a lot [35], it can be challenging to use it as input to control the game itself. Visitors could get frustrated if the system is not doing what they order it to do. Therefore, the first option is chosen; use BCI as control by affective state.

The next aspect that requires brainstorming is the output of the quiz. The output of the quiz should make visitors interested and curious. Quizzes can have many different outputs, for example, point systems, leader boards, upgrades, rewards or (personal) feedback. For this research, (personal) feedback is the most interesting choice of output, because it can be well combined with the EEG-based input. Namely, the EEG measurements can be used to provide this personal feedback.

The new findings that came up during this brainstorming phase are used to create a final concept, which is explained in the next section.

3.4 Final concept

During the ideation phase the final concept is created. The final concept is focused on game-based learning and interactivity with the visitor. The VidiNexus screen is used as the main method for interaction and communication for the application.

The concept is an interactive quiz that matches visitors to artworks inside the museum. The quiz is played via the VidiNexus screen that is placed at the entrance of the museum. This interactive and playful quiz makes the visitor aware of the different aspects of art he/she could focus on during his/her visit to the museum. When a visitor is more conscious of these aspects, the experience of art inside the museum is improved.

During the quiz, the visitor wears the Emotiv EPOC. This device measures the level of engagement when the visitor answers the questions of the quiz. The output of the Emotiv EPOC prioritizes the outcomes of the questions; when the Emotiv EPOC senses a high and positive engagement at a certain question, the outcome of that question is prioritized during the matching process. Therefore, the measurements of the Emotiv EPOC have great influence on the matched artworks to the visitor.

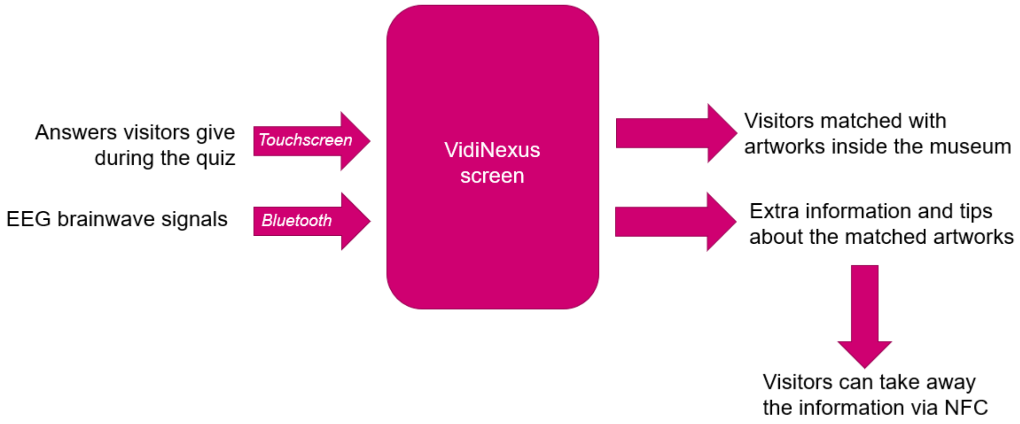

Figure 17: Schematic overview of the system

This final concept is chosen because it enhances the experience of the museum visit in several ways. The first enhancement is due to providing users an interactive experience at the start of the museum by completing the quiz itself. Additionally, the quiz provides personal feedback to the visitors which improves the experience and engagement (*Section 2.5.6*). Furthermore, by personally matching artworks to the visitors, a connection is established between the artwork and the visitor, thus increasing the visitor's engagement. Also, the quiz teaches about art aspects that are relevant for the rest of the museum visit. On top of that, the system could provide extra (personalized) tips and tricks to look at art in a different and more active way. Lastly, the concept is accessible for a broad range of museum visitors. Elderly, students and families all may have an interest in the system.

The disadvantages found in the previous concepts (*Section 3.3.1*) do not occur in this system. The system does not directly tell the user what they are supposed to feel and the matched artworks are based on the answers of the quiz combined with the output of the Emotiv EPOC. This leaves room for the Emotiv EPOC to make mistakes that remain unnoticed by the visitors. By utilizing game-based learning to teach about various art aspects, the learning aspects are integrated within the quiz. Consequently, this quiz is still interesting and intriguing for those visitors who are not interested in learning about art at all.

Chapter 4: Specification

In this fourth chapter, the final concept is further specified through user experience research and user experience scenarios. On the basis of that information, user experience requirements are stated. Following up on the user experience requirements, further specifications of the technical aspects and the visual design aspects are made. Lastly, a small pilot user test is done with the first iterations of the design to find improvements in appearance, interaction, and experience of users.

4.1 User experience

The system is designed to enhance the experience and engagement of visitors inside museums. If the experience is negative, museums and museum visitors are not interested in the system. Therefore, the user experience of the system is explored, which was done using different user scenarios. After that, the user experience requirements were created.

4.1.1 Scenario's

Multiple user scenarios were created to explore the user experiences. By using this technique, new requirements came up that may be forgotten otherwise. The personas in the alternative scenarios are from different user groups on purpose to create a broad view of the usage of the system.

Scenario 1

Susan is an elderly woman who loves going to museums or galleries. She likes museums the most when the museum is not so crowded. On a Wednesday morning, Susan visits a small art museum in the city center of Enschede, named Concordia. At the entrance of the museum, she spots the VidiNexus screen and she walks towards it. She is relieved that the system is explained via an infographic shown at the screen, as she does not know much about using new technologies. Via the infographic, Susan understands how the system is going to work. She is really curious to learn which artworks will be matched to her and what her personal profile will be. Susan puts on the Emotiv EPOC and the application begins. During the quiz, she notices that making quick decisions between the artworks is quite difficult for her. However, she manages to answer all the questions before the time runs out. At the end, the system displays the matched artworks on the screen.

Susan finds it remarkable that technology is able to do this. She is especially interested in the extra information that is given about the artworks. Also ,the extra (personalized) tips about how to improve your own experience of art are very useful for her. Unfortunately, she has no phone with an NFC function. Therefore, she is not able to take the information displayed on the screen with her. This is a huge disappointment for Susan.

Scenario 2

Jan and Bas, two students from the University of Twente are visiting the Rijksmuseum in Amsterdam. They do not have much time to spend at the museum, because afterwards they still need to go back to their home-place Enschede. However, they are both very interested in the artworks of the museum. Jan and Bas walk inside and study the floor plan of the Rijksmuseum. They did not know that the museum was this big and they do not know where to start. Therefore, they walk to an employee and ask for the best route through the museum, with the time they have in mind. The museum employees points to the VidiNexus screen and suggests that the students take the quiz to receive personal suggestions for their routing through the museum. When they arrive at the screen, they inspect the infographic and decide that Jan goes first.

Jan has experience with BCI and recognizes the Emotiv EPOC. This makes him even more excited to participate. During the quiz, Jan is able to focus and select answers pretty quickly. At the end, Jan is very excited to see the matched artworks. Next to the artworks, the system also shows where the artworks can be found inside the museum. This feature is extra useful for Jan and Bas because they do not have too much time. By knowing where the artworks are that are of interest to them, they are able to make an efficient route through the museum. Jan and Bas are very positive about the system.

Scenario 3

Maria is a young woman of 30 years old. She is a fanatic modern art fan and is very excited to go to the Voorlinden museum in Wassenaar. When she walks in, she sees another visitor standing in front of the VidiNexus screen. While walking towards it, Maria sees that the other visitor is inspecting his own matched artworks. This makes Maria even more curious about the system and her own results. When the man in front of her is done, she walks towards the screen and starts inspecting the infographic. Maria is a little hesitant when she reads about the Emotiv EPOC that measures her brainwaves. However, the infographic clearly states that the brainwaves will only be used for the quiz and will be deleted immediately afterwards. Marie puts on the Emotiv EPOC and starts the quiz. When Maria is at the end of the quiz, a row of people have gathered behind her, all eager to participate in the quiz. This makes Maria uncomfortable and she feels pressure to finish inspecting her results quickly. Luckily, there is an option to download the information displayed on the screen via NFC. Maria easily connects her phone, receives the information and happily proceeds with her visit at the museum.

4.1.2 User experience requirements

Based on the scenarios described above and the background research, multiple user experience requirements were created. Most of the requirements were created to make sure visitors feel safe and the experience is positive.

The system should make visitors feel comfortable by:

1. Providing a positive and safe experience
2. Excluding any possible negative effects
3. Providing an easy to understand system with all steps explained
4. Displaying an easy, accessible, and thereby inviting start screen
5. Not asking too much time of the visitor
6. Ensuring the visitor is always able to stop
7. Making the system not mandatory
8. Making the use of the EEG device voluntary
9. Respecting the privacy of the visitor

4.2 Technical design specification

In this section, the technical aspects of the final concept are specified further following up on the user experience requirements. The technical aspects of this system could be divided into multiple categories; the quiz, the art database and the Emotiv EPOC. These categories are explained separately in this section. Eventually, these three categories are combined to make the system work, which is done by implementing the three elements together in a Python script. Phyton [44] is a programming language that is able to work with display screens, databases and the Emotiv EPOC. Therefore the programming language Python was chosen as connecting software between the three elements for the prototype.

4.2.1 Quiz

The quiz consists of multiple questions on different screens displayed on the VidiNexus screen. To be able to display this on the screen, a set of Python modules named Pygame [45] was chosen. Pygame is designed for writing video games and allows the user to create featured games and multimedia programs [45]. This set of Python modules made displaying a quiz a lot easier and more efficient. After downloading Pygame, it can be used within Python by putting 'import pygame' at the top of the Python script [45].

Unfortunately, Pygame is not able to switch between different screens. Therefore, another feature named 'State Machine ' is used. The state machine creates different 'states' that can be displayed after each other. These 'states' are all able to have different features, functions and methods and are therefore very useful for this project.

Furthermore, a part of the code for the quiz interface came from GitHub. GitHub is an open-source community that shares data, scripts and projects with each other. The script that was used in this project is from the channel 'IanRufus' [46].

4.2.2 Database

A database of the artworks and their features should be available to match artworks to visitors. Several databases were available on the internet. These databases could have been 'borrowed' from the internet with the help of an API. However, these databases often consist of more than half a million artworks with a lot of columns per artwork. These columns are often extra information that is not useful to classify artworks and therefore not useful for the system. Also, the enormous amount of artworks that are available in these databases make the system rather slow. Therefore it is chosen to make a new (smaller) database with columns that are useful during the matching process. Columns that can be useful during the matching process are for example art style, technique, material, type of art, or colour-scene.

Python is able to work with databases via a data analysis tool (library). This tool is called 'pandas' [47] and it is built on top of the Python programming language. Pandas is able to import, read, alter, and export databases in different forms [47]. One of the database forms that pandas is able to work with is a CSV file, which can be made with the program Microsoft Excel (2013).

In the final actually produced and used stage of the prototype, the museum that uses the product needs to upload the artworks of their own museum. In that case, a database with all displayed artworks must be available or, if not present yet, made.

4.2.3 EEG device

As stated in the final concept, the output of the system is going to be a set of artworks that are matched to the user. This matching process is dependent on the choices the visitor makes and the level of engagement measured via the Emotiv EPOC.

The Emotiv EPOC sends the detected brain activity via Bluetooth to the Emotiv Pro app on a laptop [28]. Next to showing raw EEG data, the Emotiv Pro app is able to show the engagement levels of the user. Raw data and the engagement level data can be sent to the Python script of the quiz via Lab Streaming Layer [42]. The engagement levels can only be sent with a frequency of 0.1 Hz. This means that every ten seconds, a new value is received by the Python script. During these 10 seconds, the Python script is not able to perform other functions or methods.

4.3 Visual design specification

This section contains the visual design specification aspects. The visual design concerns the quiz itself and the elements inside the quiz. The interactive quiz consists of a start screen, a baseline-recording screen, question screens, and a result screen. The interface of the quiz is coded in Python. This means that having a good-looking appearance on the quiz is more difficult because coding limits the possibilities in design. Furthermore, it costs a lot of time to achieve a good design by coding.

The first iteration of the different screens and their requirements are explained and presented in the following sections. An overview of the different states with main functions can be found in *Figure 18.*

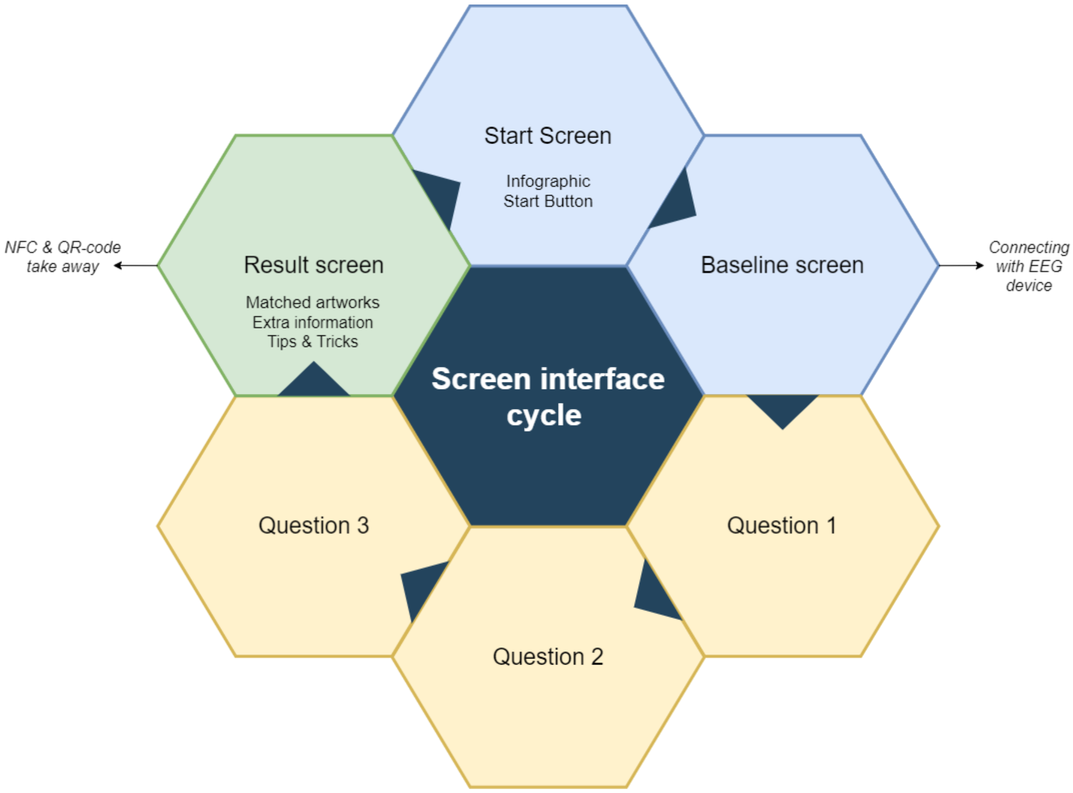

Figure 18: An overview of the different states of the quiz

4.3.1 Start screen

The start screen of the system is the screen that is displayed at the beginning of the quiz. This screen should evoke curiosity as it serves as the screen that is displayed when nobody is interacting with it yet. Therefore, the start screen should attract visitors to walk towards the screen and start the quiz.

Furthermore, the start screen should display an explanation of how the system works and what is expected from the visitors. There are several ways of displaying this information, for example through photos, video, text, or audio. For this project, it is chosen to display an infographic. An infographic is an overview with images, charts, and small amounts of text that explain the topic. An infographic is chosen because it is most suitable in a museum environment. Video and audio are, for example, less suitable because the sound can be heard by everyone and thereby could negatively influence the experience of the visitors that are not participating in the system. Furthermore, only text is also less suitable because it could scare people away, due to longer reading times or the amount of effort it requires.

Lastly, to complete the start screen, a 'Start Quiz" button must be present on the start screen. Visitors should be able to touch this button and the next screen should become visible. The first iteration of the infographic on the start screen can be found in *Figure 19.*

4.3.2 Baseline screen

This state should appear after the visitors have pressed the 'Start Quiz' button. This is a simple state where visitors are told to relax for a certain amount of seconds. This is used to create a baseline for the engagement level measurements. With the help of this baseline, the engagement level during the quiz is easier to detect and evaluate. The first iteration of the baseline screen can be seen in *Figure 19.*

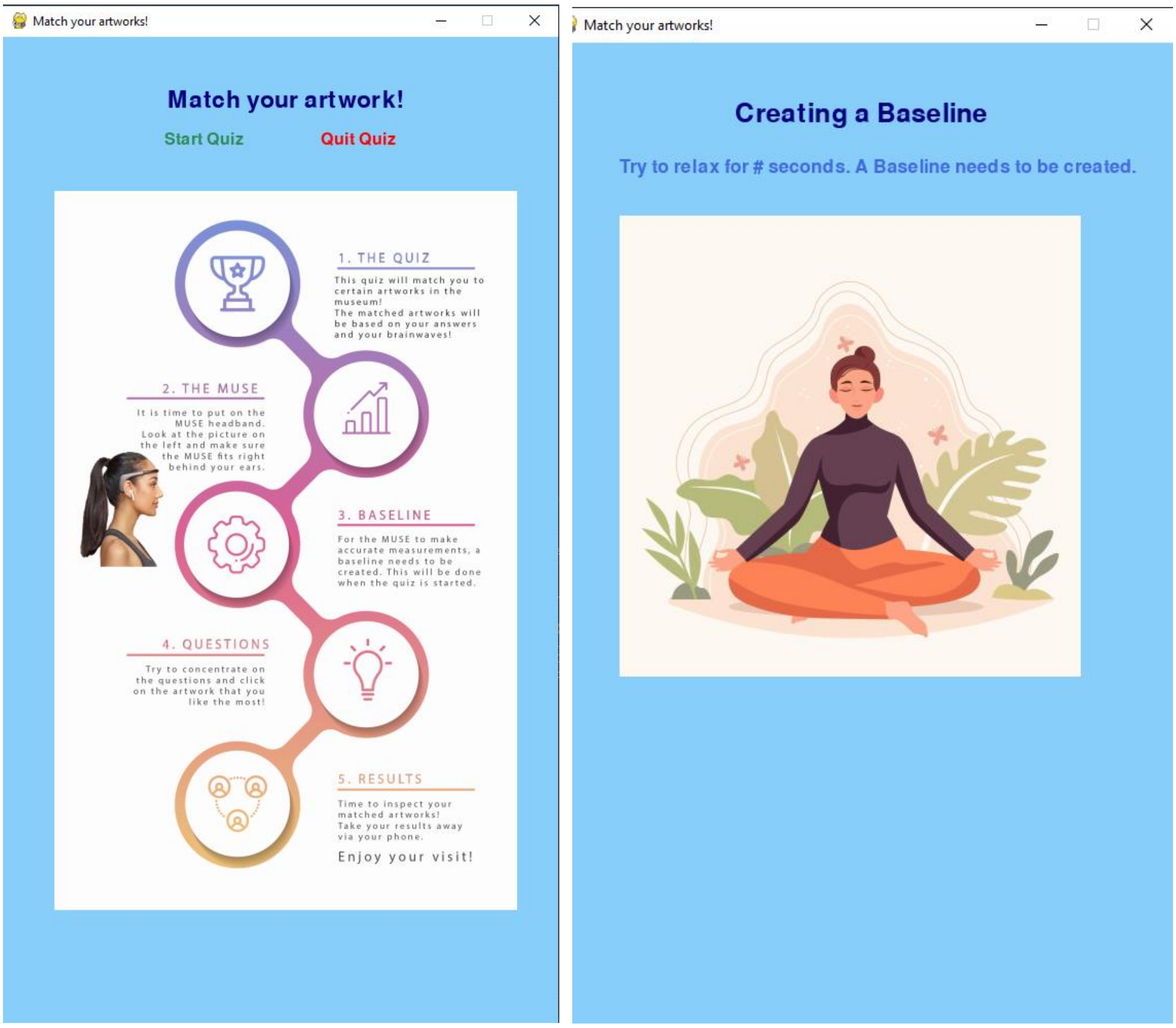

Figure 19: The first iteration of the start screen (left) and the baseline screen (right)

4.3.3 Question screen

The question screens display the question, a small explanation of the question and the artworks the visitor can choose from. The question is placed on top, with the explanation underneath. The artworks are displayed big enough so that the visitors are able to inspect details of the artworks.

The amount of questions is not yet determined. Amongst other things, this depends on the final database that is used and what kind of columns that database has. Naturally, the quiz should not contain too many questions, as visitors could lose attention if the quiz is too lengthy. Furthermore, the system is used at the entrance of a museum, therefore, if the quiz takes much time, not everyone is able to participate because the waiting line could be too long. On the other hand, if the amount of questions is too small, the system is not able to correctly match artworks to the visitor. The right amount of questions is investigated during the evaluation phase of the project. Furthermore, the form of the questions needs to be specified. Quiz questions can have lots of different forms; multiple-choice, true/false, fill-in blanks, open/closed-ended questions, sequence questions or classify questions. For simplicity and consistency, the first prototype has only multiple-choice questions. In *Figure 20*, the first iteration of a question screen can be found.

4.3.3 Result screen

The result screen is the last screen visitors see. This screen shows the matched artworks to the visitors. Additionally, extra information about these artworks and extra tips for the rest of the visit are displayed. The extra information can, for example, also be linked with a button on the screen which takes the visitor to another webpage. Furthermore, visitors should be able to take the information and artworks displayed on the screen away via NFC or a QR code. This should be explained on the screen. The first iteration of the result screen can be found in *Figure 20*.

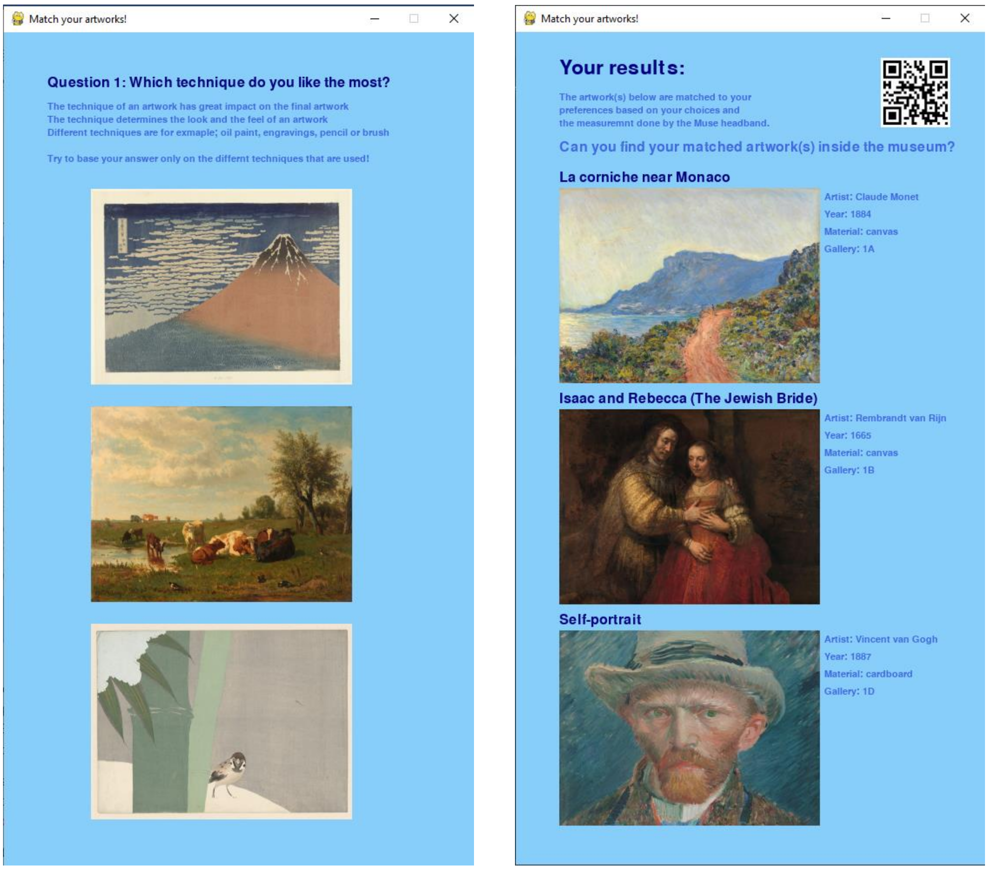

Figure 20: First iteration of a question screen (left) and the result screen (right)

4.4 Pilot test: Design specifications

The goal of this pilot test was to find out what aspects of the interface and the content of the quiz could be improved. This pilot test was not yet focused on the interaction because the test is done on a laptop without the EEG system. Therefore, the pilot test was fully focused on the appearance, understandability, and information displayed on the screens. The findings of the pilot test are used to improve the system during the realisation phase (*Chapter 5*).

Since the product aims to serve the diverse group of visitors of museums there were no limitations for participants. Preferably, the participant group exists of different ages and interests. However, due to the CoVid-19 situation, this was hard to achieve. Therefore, the participant group consists of housemates and friends (students). Since it was a user test situation, the ethical committee required that all participants in the pilot test to be above 18.

The protocol of the pilot test is as follows:

1. The participant reads the information brochure and signs the consent form. If the participant does not want to sign, the test is stopped immediately.

2. The participant inspects the start screen of the quiz and reads the infographic.
3. The participant answers the questions about the start screen.
4. The participant continues the quiz and answers the quiz questions
5. The participant answers the questions about the quiz question screens.
6. The participant inspects the result screen and the matched artworks.
7. The participant answers the questions about the result screen
8. The participant answers the general questions
9. Open discussion between researcher and participant

As can be derived from the protocol described above, the questions that were asked are screen-specific. The questions are filled in by the participant via Google Forms. The answers can be given on a Likert scale from 1 to 5, or in a short open text block. The specific questions that were asked can be found in *Appendix F.*

4.4.1 Results pilot test

The results of the pilot test are stated below. The test was done with six participants. Overall, most of the questions about appearance were negatively answered. This was expected since the design is done through coding. During the realisation phase, more time is spent on designing and the interface is improved. The exact findings can be found in *Appendix G*. The sections below state short summaries of the pilot user test findings.

Start screen & Infographic

According to the participants, the start screen does not achieve the attention level it should have. Two participants came up with the same idea separately; they suggested that there should be a start screen that displays the title and random artworks. After the start screen, a different screen should be displayed with the infographic on it. This could improve the attention the system gets when it is standing in a museum.

Furthermore, the pilot test asked questions about the infographic. The question about the clarity of the system after inspecting the infographic is answered very positively. This means that the information on the infographic is fine and explains the system well. However, there were also some questions answered more negatively. For example, one participant stated that the infographic shows too much text and too little figures. Another tip that was given was about the icons. Two of the five icons do not match that specific part of the infographic. These aspects can be improved in the realisation phase.

Question screens

The next questions of the pilot test were about the question screens. Overall, participants found the question screens very clear. The text was clear and the participants liked the art aspects the quiz was about. One participant recommended adding an extra question about the time period of the artwork. Additionally, the question about the learning aspect of the quiz was answered with a 3.5 on average (on a 1 to 5 Likert scale). Recommendations were given to implement an extra button that provides even more information about the displayed artworks or the art aspect of the question.

Result screen

Overall, participants graded the clarity of the results very positively. All participants answered that they would like to visit the matched artworks in the museum. Additionally, participants were positive about the quiz forming a better connection between them and the artworks. On the other hand, some of the participants stated improvements for the system. The participants would like to know more about why these certain artworks are matched to them, and to which art aspects the artworks belong to. This could be relatively easily improved during the realisation phase.

General questions

The last part of the quiz asked some general questions about the whole quiz. All participants answered that they liked to participate in the quiz. Furthermore, some recommendations were given. The participants wanted to see a more appealing and professional design of the whole system. Additionally, one participant had a comment about the user interaction. Currently, the quiz is controllable via buttons on the keyboard. This participant would like to control the game by moving and clicking the mouse. These options are explored during the realisation phase.

Chapter 5: Realisation

This fifth chapter states the realisation of the art-visitor feedback system. The prototype is realised conforming to the specifications, as described in the previous chapter, including the recommendations of the pilot test in the specification phase (*Section 4.4*). In this research, the prototype of this system uses a laptop to display the interaction with the visitor instead of the intended VidiNexus screen. This is done to focus the research on optimising the actual interaction with the visitor, rather than controlling the large monitor. The interaction, and thus improving the user experience and accuracy of the system, can just as well be done on an easy-to-control laptop, which increased the efficiency of the research considerably.

Just like the specification phase, the realisation phase is divided into two sections; technical realisation and design realisation.

5.1 Technical design realisation

This section describes the realisation of the technical aspects of the system. The functional architecture structure, the logic flow chart and the database are presented and explained. Each section presents more details of the system.

5.1.1 Functional architecture structure

The functional architecture structure identifies the functions and interactions of the system. The main function of the system is to make an art recommendation for the users by the means of an interactive quiz and using the engagement levels measured with the Emotiv EPOC during the quiz. Since the quiz is made in Python [44] using Pygame [45] and the library 'Statemachine', the system has many different classes. Most of the classes define a different screen of the quiz. Furthermore, there are some extra classes needed to pass information between the classes and determine the order of the screen classes.

A graphical representation of the entire technical structure is shown in *Figure 21*. The blue blocks represent the different classes within the Python script. Light blue (Main, Game and Base) means that no interaction with the user is required. These classes are needed to pass information between the other classes. On the other hand, the darker blue classes do require interaction from the user to proceed to the next screen of the quiz. The green block displaying 'Database' represents the Microsoft Excel art database. Lastly, the yellow and red blocks represent the connection between the Emotiv EPOC and the rest of the python code. To conclude, *Figure 21* roughly sketches the relations between the different classes and the other components needed for the quiz.

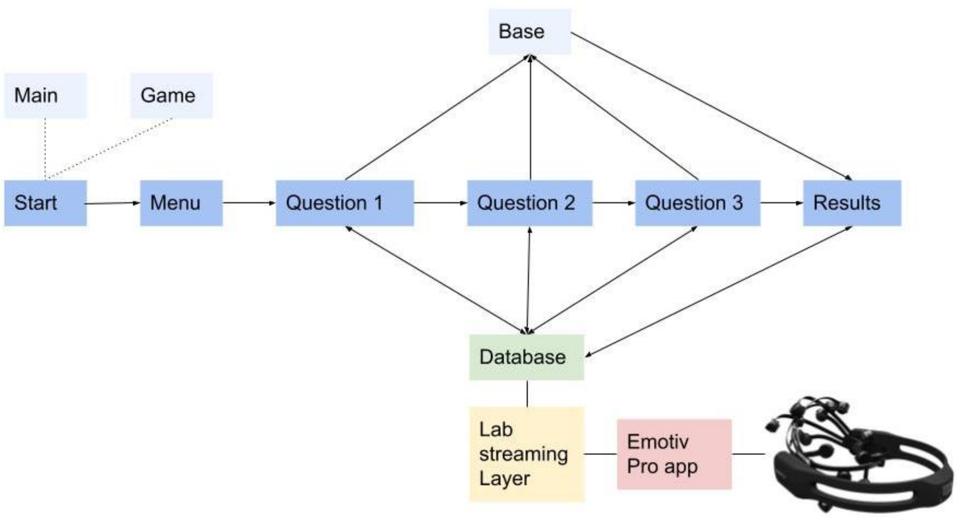

Figure 21: Simple sketch of the functional architecture structure

Assumptions made in earlier stages of the research about the need for a baseline class are not correct. This is because the engagement levels that are measured are only compared to each other; the engagement levels measured during question 1, are compared to the measurements during questions 2 and 3. The question with the highest engagement levels receives the most value during the matching process. This means that the measured engagement levels are not compared to other users. Therefore, a baseline measurement does not have any added value anymore and the class can be removed from the quiz.

5.1.2 Logical flow chart

In the logical flow chart, the functional architecture structure (*Figure 21*) is further elaborated into more detail. This is done to clarify the functions and features of the code. In the flow chart (*Figure 22*), the most important structures, features and functions of the code are visualized. Additionally, the relations between the classes are displayed and the interactions are shown.

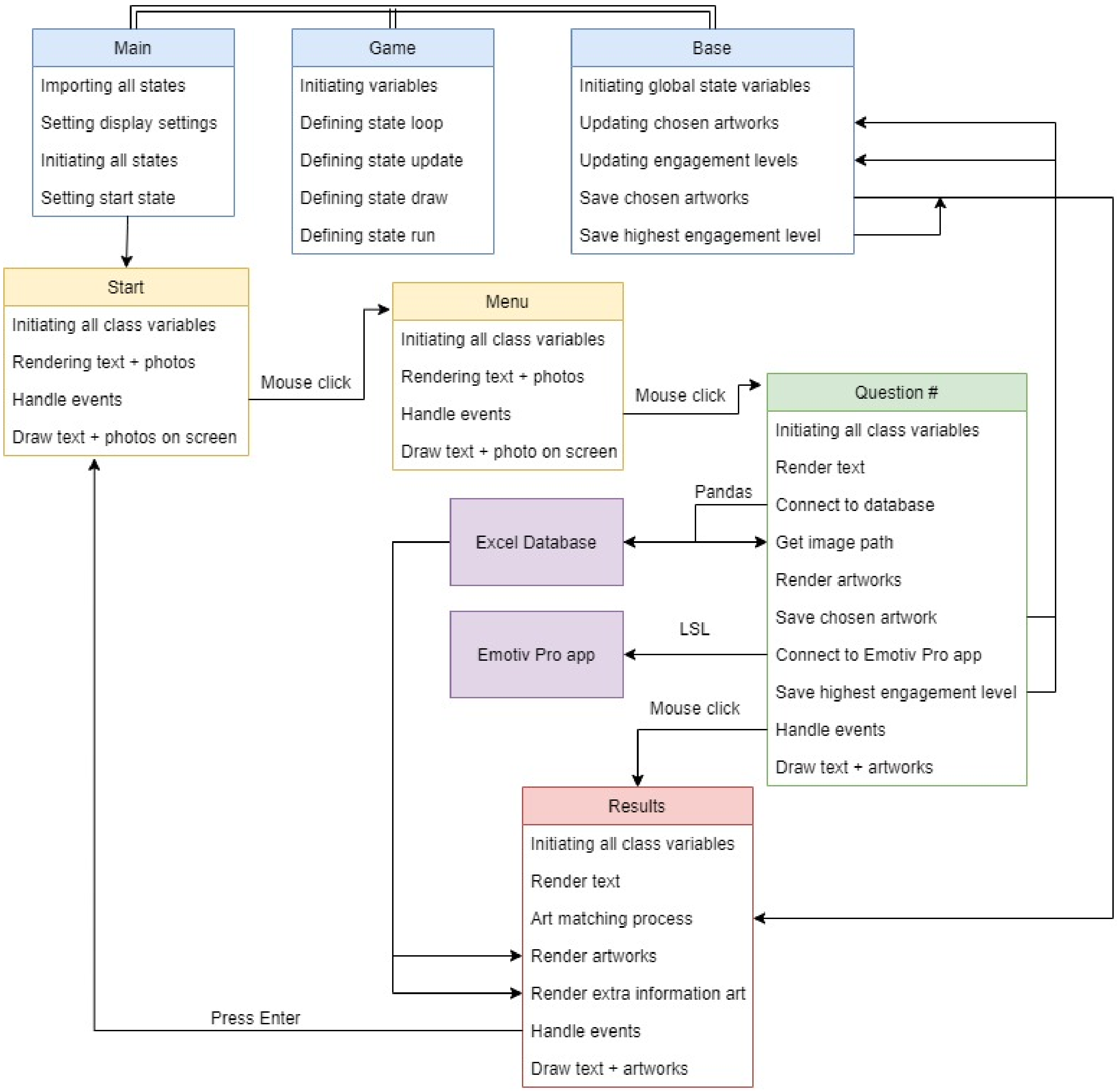

Figure 22: Logical flow chart of the code

A short explanation of the different classes is given in this paragraph. The three light blue classes do not require any interaction from the user. The class 'Main' determines the order and the basic settings of the displayed screens. The 'Game' class is a parent class for all interaction classes in which the order of methods and functions are determined. The class 'Base' is used to save values important for the matching process. The question screens pass the measured engagement levels and the chosen artwork to the 'Base' class. The class 'Results' collects these values from the 'Base' class to determine the matched artworks.

The other classes (all classes except Main, Game and Base) do require interaction with the user. This interaction is needed to proceed to the next screen and/or choose a favourite artwork. In the specification phase, this interaction was done by pressing buttons on the keyboard. However, during the pilot test (*Section 4.4)* it was found that the interaction was not very natural. Therefore, the interaction between the user and the system is improved and can now be done by moving and clicking with a computer mouse.

As can be seen in *Figure 21* and *Figure 22*, the Emotiv Pro app is connected to the quiz using Lab Streaming Layer [42]. The engagement levels are sent from the Emotiv Pro app to the Python script when the question screens are being displayed. Three engagement level values are sent. Because the frequency is 0.1 Hz, sending three engagement level values takes 30 seconds. This means that the program is not able to perform any other functions or methods during 30 seconds.

The entire python script can be found on Github via the link stated in *Appendix H.*

5.1.3 Art database

The database with the artworks displayed inside a museum is made with the program Microsoft Excel (2013). The database consists of 50 artworks. These artworks originally come from the online art database of the Rijksmuseum Amsterdam in The Netherlands [48]. The columns are filled with information that originates from the same database. Additionally, the images of the artworks are downloaded via the same website.

Since the database is stored locally on the computer, also the images need to be stored locally. Therefore, the image path towards the correct location of the image is copied into the column; 'Image'. This column can be called from the python script to show the correct image on the screen.

The columns that are included in the databases are:

- Artwork
- Artist
- Dating
- Place (Where the artwork is made)
- Material
- Technique
- Object type
- Theme
- What (the objects that are displayed)
- Color scene
- Colors
- Gallery number (of the Rijksmuseum)
- Website URL (Link to get more information about the specific artwork)
- Image

As an example, the first ten lines and columns of the art database can be seen in *Figure 23.* The whole database is stated in *Appendix I*.

	A	B	C	D	E	F	G	H	I	J
1	**Artwork**	**Artist**	**Dating**	**Place**	**Material**	**Technique**	**Object_type**	**Theme**	**What**	**Color_scene**
2	The Night Watch	Rembrandt van Rijn	1642	Amsterdam, Holl	canvas	oil on canvas	painting	portret	warfare, weapons, drun	dark
3	Isaac and Rebecca (The Jewish	Rembrandt van Rijn	1665		canvas	oil on canvas	painting	portret	marriage	dark
4	Oopjen Coppit	Rembrandt van Rijn	1634		canvas	oil on canvas	painting	portret	historical_person	dark
5	Self-portrait	Vincent van Gogh	1887	Paris, France	cardboard	oil on canvas	painting	portret	portrait, historical_pers	colorfull
6	Farm in Provence	Vincent van Gogh	1888	Provence, France	paper	pen and brush	drawing	cityscape	folkcostume, cityview	light
7	Irises	Tsukioka Kugyo	1890	Japan	paper	colour woodcut	print	landscape	flowers	colorfull
8	Souvernir de la Provence II	Lodewijk Schelfhout	1943	Provence, France	paper	engraving	print	cityscape	cityview, landscape	light
9	Floral still life	Hans Bollongier	1639		panel	oil on panel	painting	stilllife	flowers, still life	colorfull
10	Girl in a white kimono	George Hendrik Breitner	1894	Amsterdam, Holl	canvas	oil on canvas	painting	portret	historical_person, dress	colorfull

Figure 23: Screenshot of part of the art database

5.2 Visual design realisation

This section describes the realisation of the visual design aspects of the system. The improvement opportunities that came up in the pilot test (*Section 4.4)* are integrated into the final designs. Additionally, some technical changes, such as the baseline screen that is deleted, are also processed in the design realisation.

5.2.1 Infographic

The final design of the infographic looks like the design shown in *Section 4.3.1.* However, some changes needed to be made. As explained, a baseline screen is not necessary anymore. Therefore, the baseline explanation in the infographic is removed. Furthermore, for the EEG measurements to work, the system should have 30 seconds without any interactions. The participant should be aware of this function. Therefore, an explanation of this is added to the infographic. Additionally, icons within the line graph are changed to prevent confusion. The improved infographic can be found in *Figure 24*.

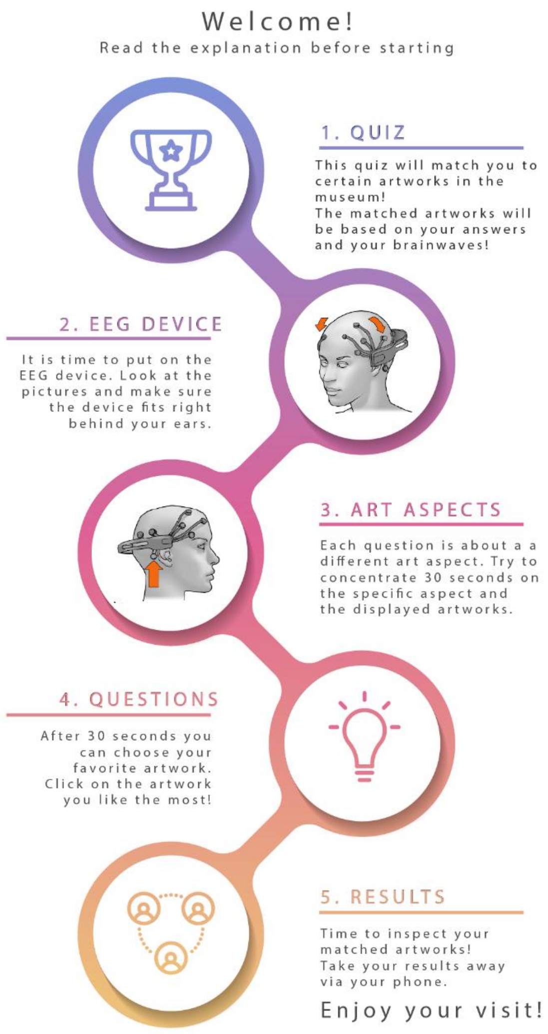

Figure 24: Last iteration of the infographic

5.2.2 Quiz interface

The quiz interface has been changed multiple times during the realisation phase. Firstly, the start screen presented in *Section 4.3.1*, is divided into the start screen and the separate menu screen, due to recommendations given in the pilot test (*Section 4.4).* The start screen is meant to seek attention and the menu screen displays the infographic. These changes are done to make the quiz look more inviting for visitors to start interacting with it. Secondly, the background of the screen is adjusted to make the screens look more appealing. Additionally, the size of the text is adjusted to make the screen more playful. The newly designed screens can be seen in *Figure 25* and *Figure 26*.

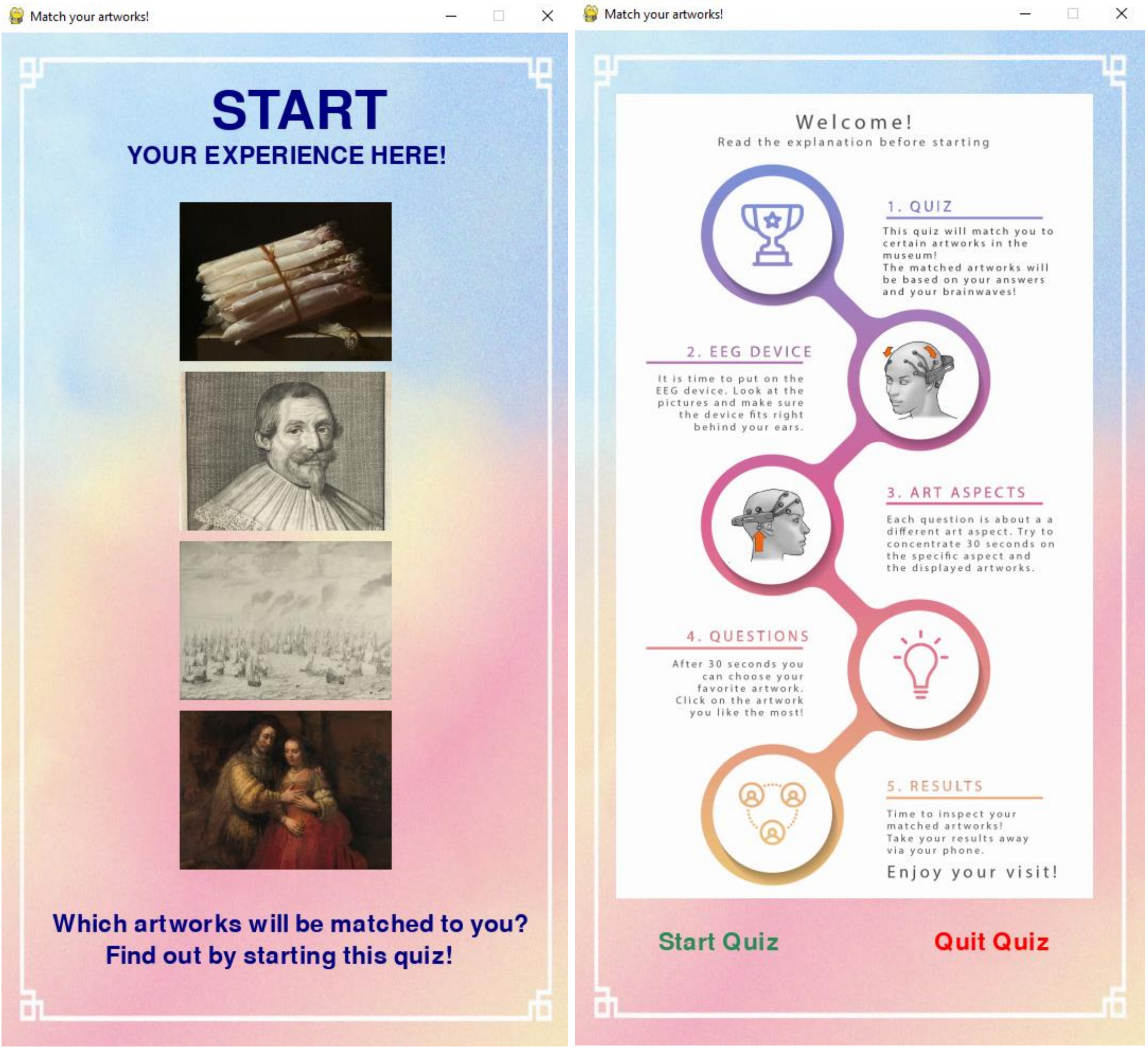

Figure 25: Last iterations of the start and menu screen

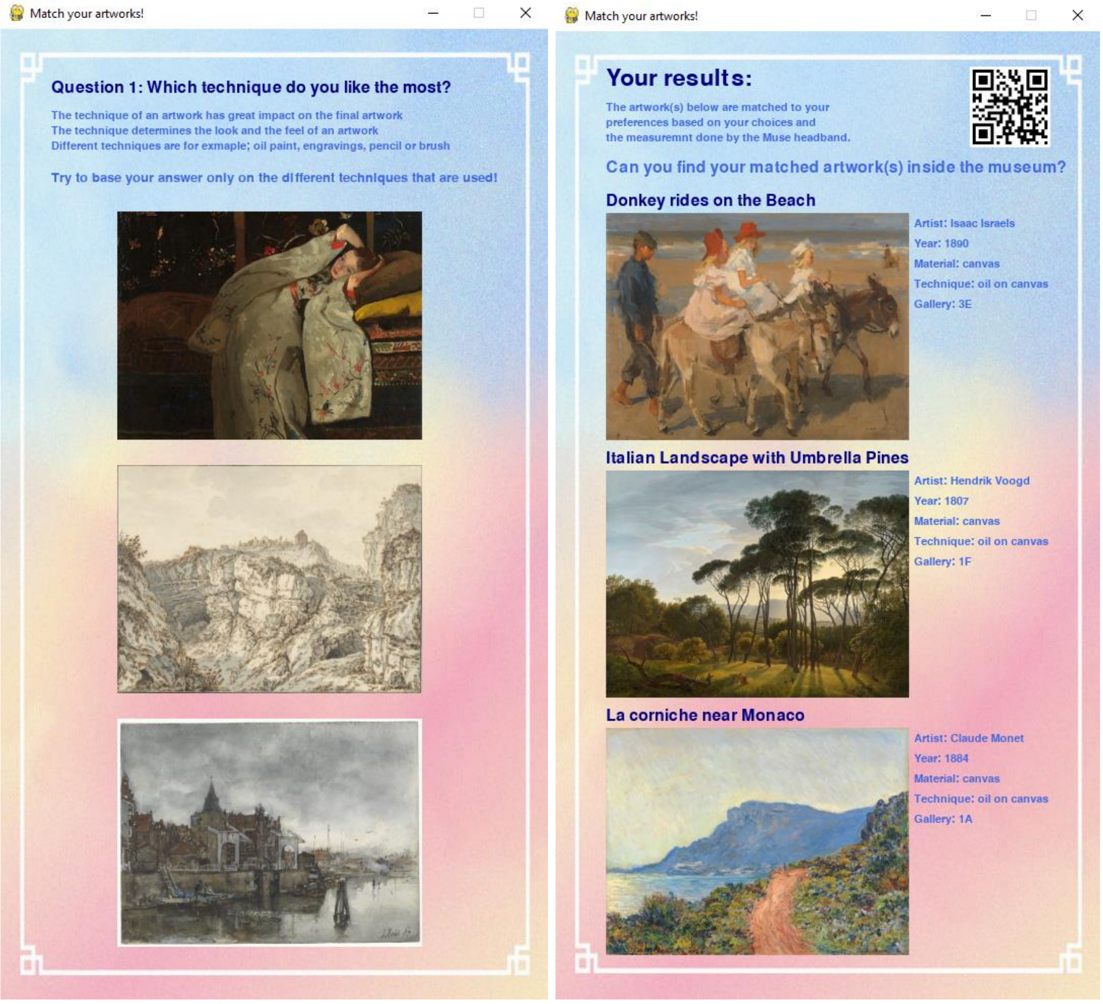

Figure 26: Last iterations of the question and result screen

Chapter 6: Evaluation

To evaluate the final project, user tests were executed on the developed prototype of an art-visitor feedback system. The user tests aimed at proving the feasibility of the concept, from which conclusions and recommendations for future work were drawn. The concept was considered feasible if it both proves to be technically feasible and adds the intended value.

6.1 User Testing 1

The user test is seen as a proof of concept. This means that the main goal of the first user test was to find out how accurate the art recommendations to the visitors given by the system are. This was tested with a survey and the Emotiv EPOC engagement level measurements. The survey was used to get subjective answers to the accuracy of the recommendations and the Emotiv EPOC was used to get objective results to the accuracy of the recommendations. Furthermore, the user test explored the user interactions and experiences during the quiz and thereby found improvements for the system. This was tested with questions in the survey and observations of the researcher. Additionally, the secondary goal of the system; to teach visitors about certain aspects of art and to ensure visitors feel more connection with artworks, was also investigated. Again, this aspect has been tested through the survey.

The user test required the setup of the Emotiv EPOC, which took a significant amount of time, as it needs to be ensured that there is good contact quality between each individual electrode and the user's head. Therefore, the estimated time for one user test was around 40 minutes (as described in the protocol below). The first user test is done with 16 participants. All participants were above 18, and an equal ratio between men and women was maintained. Furthermore, the participants that participated in the user tests were all students. This is due to the Co-Vid 19 regulations, which made it difficult to have a participant group with different ages and interests. Moreover, if the test would have been done with participants of multiple different ages and interests, and the participant group would only consist of 16 people, it would have been difficult to draw accurate conclusions.

The user tests were done using a laptop and a monitor. The quiz was displayed on the monitor and the laptop was displaying the survey. Furthermore, the Emotiv EPOC was applied to detect and measure the brainwaves of the participant. The equipment (Emotiv EPOC, laptop, keyboard and mouse) was cleaned after each test to minimize the Corona risks. The information brochure and the consent form can be found in *Appendix J.*

The protocol of the user test was as follows:

1. The user reads the information brochure and signs the consent form (if the user does not want to sign the consent form, the test is not be continued). (5 min)
2. The researcher gives additional information about the Emotiv EPOC (3 min)
3. The researcher helps the user setting up the Emotiv EPOC (10 min)
4. The researcher checks the setup (2 min)
5. The researcher starts the program (1 min)
6. The user interacts with the program and the researcher observes (5 min)
7. When the results are shown, the participant takes off the EEG device (2 min)
8. The researcher screenshots the engagement level values (1 min)
9. The researcher opens the survey on Google Forms (1 min)
10. The participant answers the questions (10 min)
11. The researcher thanks the participant and thereby ends the user test (1 min)
12. After the test, there is the opportunity for an open discussion between user and researcher

The questions asked in the survey can be found in *Appendix K.* Besides the survey that is filled in by the participant, also observations during the test are done by the researcher. These observations help to study the spontaneous behaviour of the participant. In this way, potential errors in the interaction between the system and the participant could have been found. The observations were done with the help of a table. In this table, observations are stated and the number of occurrences is tracked. Furthermore, if a new observation was made, it was added to the table. The table can be found in *Appendix L.*

Additionally, the engagement levels of each participant were saved and added to the same table. The engagement levels are used to see if, and how big, the differences in engagement of each participant are between the different questions. This information is needed to answer a goal of the user test, to determine whether it adds enough value.

6.2 Results user-test 1

The user test is carried out with 16 participants with an equal ratio of men and women. The results are divided into three groups; survey results, observations and engagement level measurements. *Figure 27* provides a picture of the experimental setup. The participant was wearing the Emotiv EPOC and was reading the infographic displayed on the screen.

Figure 27: The experimental set up

Survey results

As said in the previous section, the survey provided insight into the user experience and the matching accuracy of the quiz. A summary of the results of the survey can be found in *Table 3.*

Table 3: Results of the user-test survey

What	Results	Tops	Tips
Start screen	14 were very curious about the system, 2 indifferent; 13 would walk towards the screen & 3 maybe	+ Good layout	Add brainwave system on start screen; Make it clearer where to click to start;
Infographic	13 found infographic appealing & 3 middle	+ Good style + System very clear after reading + all exited to start	Remove white background; Text a little bigger;

	14 understand system completely after reading & 2 a little		Explain purpose more;
Question screens	14 wanted more questions & 2 stated that it depends on circumstances	+ look good + all liked the art questions	Distracted by reading;
Learning factor of art aspects	8 learned something, 6 not really/no & 2 indifferent	+ Liked the art aspects	Make experience longer; Display aspects at each painting;
30 seconds waiting time	12 no problem concentrating, 4 a bit too long	+ forces you to concentrate	Display timer
Connection with artworks	8 more connection, 5 equal & 2 not more connection		
Results (Matched artworks)	11 would like more information, 3 maybe, 2 stated it was good 12 would take information away (QR/NFC), 3 maybe & 1 not		Add message behind it; Add short description Make more clear why these artworks are chosen;
Interactions		+ very natural interactions	Switch start & quit buttons;
Emotiv EPOC	13 wanted more information about brainwaves and the device & 3 maybe	+ improves the experience a lot!	Display more info about brainwaves and EEG; Add EEG feedback during quiz;
General questions	14 would recommend the system to others, 2 maybe	+ described as fun, interesting, nice, exciting and cool	

The most important user feedback was that the EEG device is too invisible. Although the users wore the device, it was not clear to them what the measurements are really doing. In the feedback, it was stated multiple times that it would improve the experience a lot if (more) EEG feedback would be given during or after the quiz.

According to the survey, the accuracy of the matching artworks is 77%. This means that on average 77% of the artworks are matched well and the participant liked the artworks that were chosen for them. This was calculated by dividing the amount of matched artworks by the amount of liked artworks per participant. After that, the average value of the individual percentages was calculated, which resulted in 77%.

The last result that can be stated is that the database proved to be too small. This can be concluded because sometimes a participant had only one matching artwork matched. When only one artwork is matched, the database did not have any other artworks that match the specific choices of the participant. The database does not include all different combinations of technique, theme and colour-scene a minimum of three times and is therefore too small. This could also affect the experience and accuracy of the test, as the participant should like the one artwork that is matched or the matching accuracy is immediately 0%. Additionally, the user experience drops when the artwork that is matched is not liked by the participant.

Observations

The observations were done during the user test. The first aspect that was observed was the setup of the Emotiv EPOC. The researcher helped all participants with putting on the Emotiv EPOC in the correct way. However, for five users (mostly users with long and thick hair, see *Figure 28*) the Emotiv EPOC would not receive a sufficient signal even after 20 minutes of trying. These users did the user test with the Emotiv EPOC on, however, the brainwaves had no influence on the results of the quiz.

Figure 28: Participant with too long/thick hair for the Emotiv EPOC to receive accurate signals

The second aspect that was notable during the user test was that 9 users clicked on the preferred artwork before the 30 seconds, in which the engagement levels are measured, were over. This could be expected as there is no signal indicating when the measurements have been completed. When the user clicked on the artwork before the 30 seconds were over, the system displayed a loading sign. This made some users confused which made them ask a question. This could have influenced the results. As also stated in *Table 3* ('Tips' column), a timer which displays the 30 seconds could resolve this problem.

The last aspect that was notable during the user test was that none of the users looked away during the quiz. This observation could indicate that the completed measurements are solely dependent on the screen and the quiz. This cannot be said definitively, as there is no way of knowing if the users' thoughts were actually focused on the quiz. However, by observing that no participant looked away, it can be stated that the influence of other factors on the measurements is minimal.

Engagement levels

From the 16 participants, five measurements are not useful, due to insufficient contact quality. The Emotiv Pro software only calculates the engagement levels when all electrodes have a good signal. If only one of the sensors is not connected correctly, the engagement levels are not calculated. For three of those five participants, who did not have useful measurements, one of the sensors could not get connected correctly. Even after trying for more than 20 minutes, switching electrodes, or providing more conduction water, the sensors would not receive a sufficient signal. Therefore, the user test was carried out without any EEG input. Another participant had exactly the same engagement levels at the three measurement points at the second and third questions, all 0.9465. This is extremely unlikely and suggests that there was some problem causing the Emotiv to measure the exact same results over a 30-second time span. These measurements are therefore considered invalid/incorrect. For one participant the measurements cannot be used, as they were not saved properly due to a human error. Therefore, only 11 measurements of the Emotiv EPOC are evaluated.

In *Figure 29*, the engagement levels measured by the Emotiv EPOC are displayed. The Y-axis presents the measured engagement levels and the X-axis presents the quiz question. As can be seen, most of the engagement levels are highest at the first measurement of each question. This could be because the first measurement is carried out during the time that the user is reading the question and explanation of the question. Another reason could be that the user's concentration is best at the beginning of the 30 seconds, which leads to a higher engagement at the start. These factors could influence the accuracy of the matching process. Therefore, further research is necessary to explore the influence of reading the question while the measurements are taking place

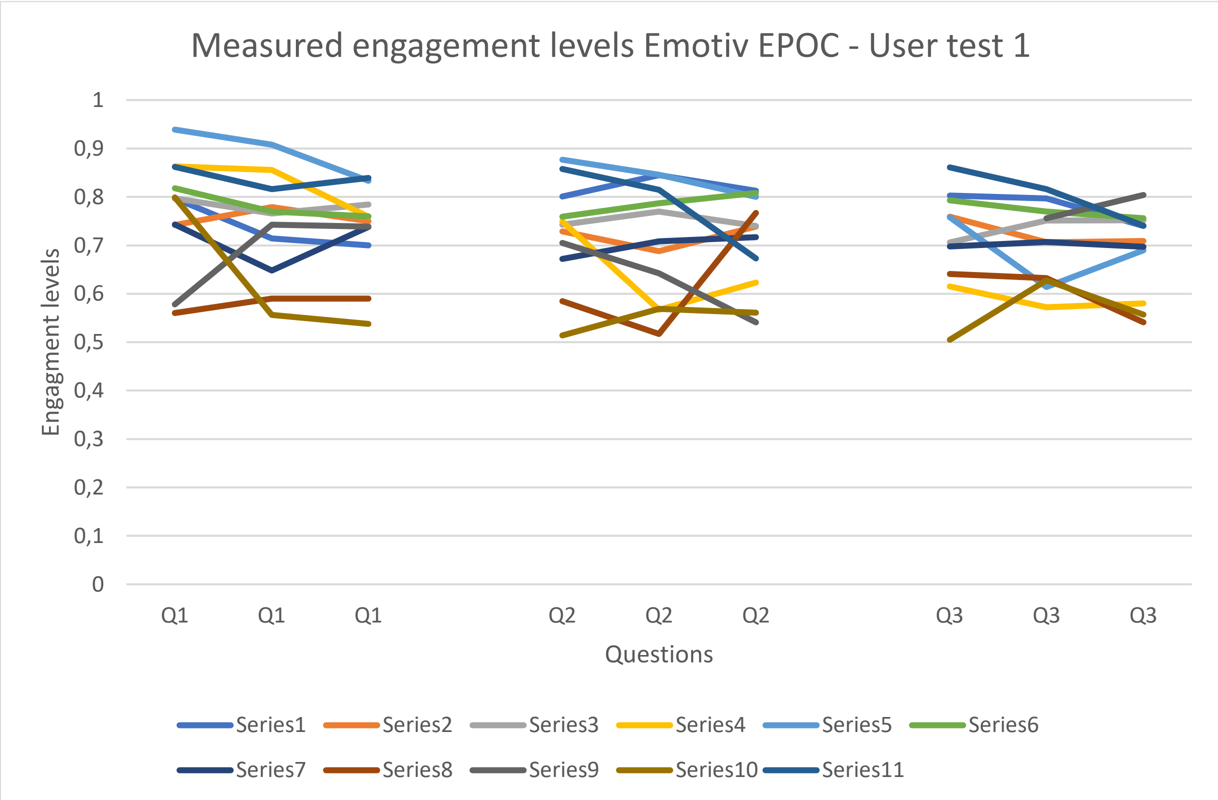

Figure 29: Graph of the Engagement level results user test 1

Other observations that can be made, are derived from *Figure 30.* This figure displays the average engagement levels during the whole test. Again, the Y-axis presents the measured engagement levels and the X-axis presents the question. As can be seen, the average of the engagement levels drops between the start of question 1 and the end of question 3. At eight of the 11 participants, the first question had the highest engagement and thereby had the most influence during the matching process. Furthermore, the average engagement levels also shows the potential influence of reading a question very clearly. The average engagement levels at the beginning of a question are higher than the levels at the end of a question. To explore the influence of reading, a second user test is needed.

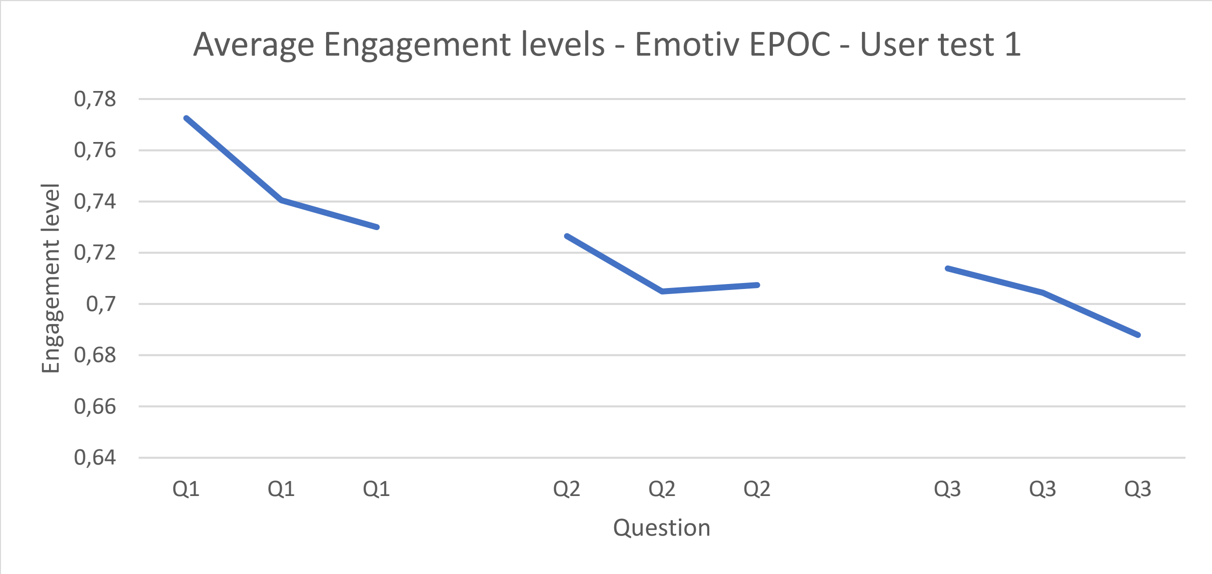

Figure 30: Graph of the average engagement levels - user test 1

6.3 User Testing 2

To be able to give better answers to the research questions of the user test, a second round of testing is done. This second user test was focused on the influence of reading a question while the engagement measurements are already started. The goal of this test was to find out if the engagement level measurements are different than the engagement level measurements done in User test 1.

To be able to find new answers, the quiz has been altered. Extra explanation screens were added before every question screen. This way, the user was able to read the question and explanation of the art aspect before the engagement level measurements started. When the user was done reading, he/she could click on the screen to progress to the next screen, displaying the three artworks. When the screen with artworks was shown, the measurements started.

Furthermore, some other improvements are made based on the recommendations from the survey. First, a picture of EEG measurements is added to the start screen to make users more curious about the system and the brainwave measurements. Secondly, it has been clarified how to start the quiz on the start screen. Lastly, the buttons 'Start quiz' and 'Quit quiz' are switched for more natural interaction. These improvements were made, as they were relatively easy to implement and did not significantly alter the structure of the quiz. Therefore, the reading influence could be investigated and data from the second test could be compared against the first test.

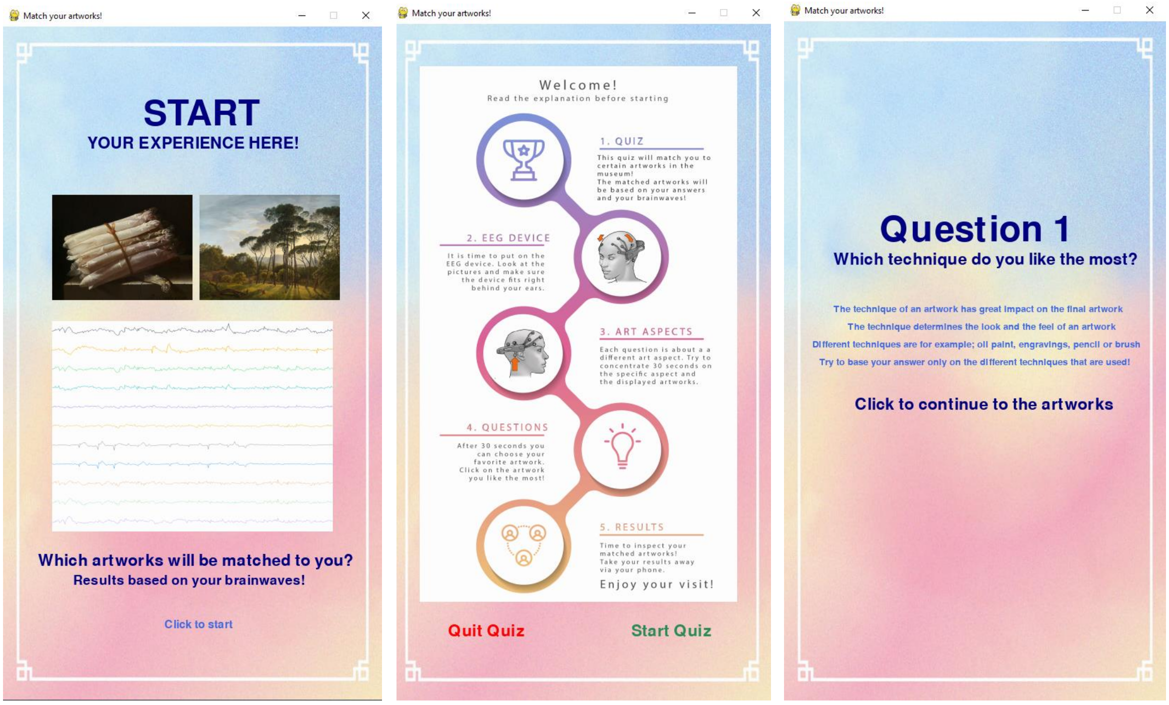

Figure 31: New implementations of the screens for user test 2

The protocol remained exactly the same as in user test 1. Additionally, also the user group requirements remained equal to test 1. Only the survey contained different questions. These questions can be seen in *Appendix N.*

6.4 Results user-test 2

This second user test was done with 6 participants. Unfortunately, the objective data of participant 4 is missing. This test was done with only 6 participants because the differences between the first user test and this test were already clearly visible in the results. The participants that participated in the second test also participated in the first test. This has no impact on the reliability of the results, as the test was not comparing engagement values between test 1 and test 2. This test was solely interested in the trend of the engagement values throughout the quiz. The results are divided into survey results and engagement level measurement results.

Survey

According to the survey, the accuracy of the matching artworks is 56%. This means that on average 56% of the artworks are matched well and the user liked the artworks that were chosen for them. This percentage could be lower because the second user group is smaller than the first user group. With a smaller user group, the test is more sensitive to fluctuations in the results. For example, one of the participants had a 0% score of artworks that were liked, this result had a much higher impact on this smaller user group than it has on a bigger user group.

Other questions in the survey were about the interaction of the quiz. All participants found the interaction with the system natural and there were no more comments about for example the place of some buttons.

The last question of the survey asked about the concentration levels of the participants during the quiz. Four participants felt that their concentration was best at the beginning of the thirty seconds. Furthermore, one participant stated that it was equal throughout the quiz and the last participant stated that their concentration was best at the end of the thirty seconds.

Engagement levels

The engagement levels can be seen in *Figure 32*. As can be seen, the decreasing value effect within each separate question and between the questions, that occurred in user test 1, is not visible in these results. The engagement levels are more random. Additionally, this effect is also visible in *Figure 33.* This figure displays the average engagement levels of the six participants during the different questions.

Another aspect that can be seen in these results is that measuring engagement levels failed for one participant (*Figure 32*, Series 4). The Emotiv EPOC did not receive any useful brain activity anymore after the second half of the second question. This is probably due to poor contact quality between the electrodes and the head of the participant.

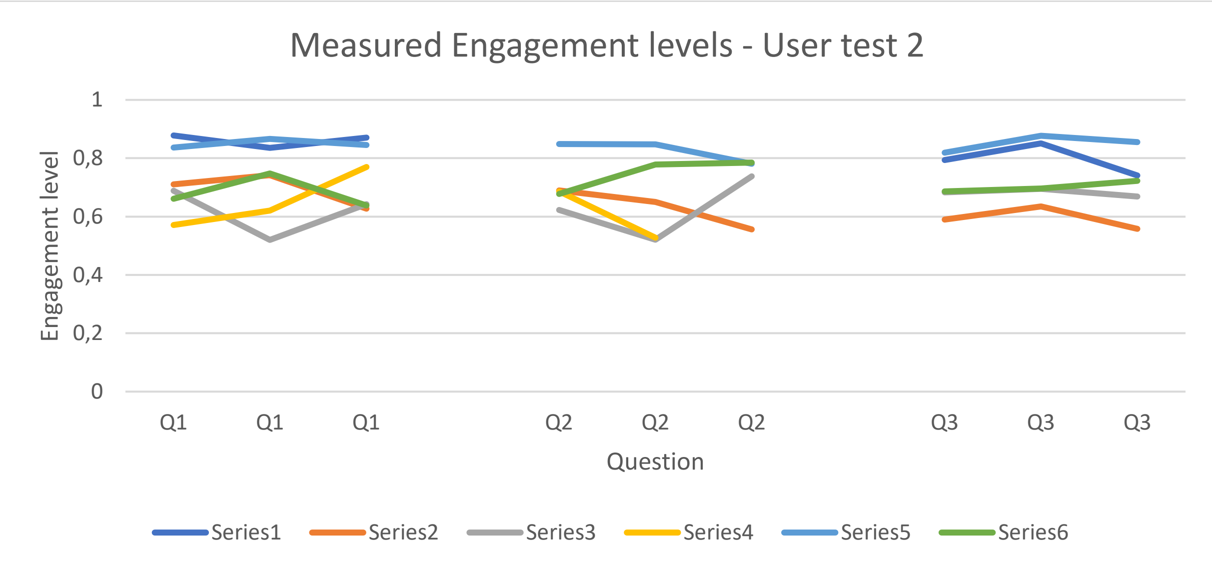

Figure 32: Graph of the engagement levels results of user test 2

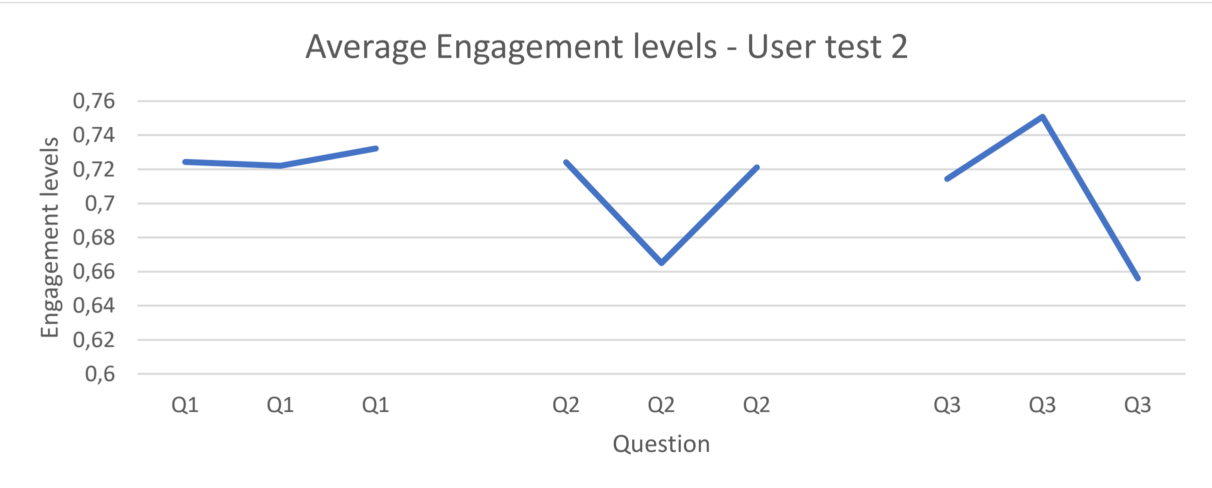

Figure 33: Graph of the average engagement level results of user test 2

6.5 Conclusion user-tests

This section concludes with the feasibility of an art-visitor feedback system based on two user tests. It thereby concludes the third topic of the research; the prototype. This section first summarizes the conclusions of user test 1 and user test 2 and gives a general conclusion.

Conclusions user test 1:

To start with the positive feedback. The participants stated that the concept of the quiz is really fun and intriguing. They all liked participating in the quiz and they would all recommend the system to others if the system was placed in a real museum. Furthermore, the interaction felt natural to almost all participants and they liked the layout of the quiz. Additionally, almost all participants stated that the experience of the quiz is really improved by the fact that their brainwaves were part of the matching process.

However, there are also aspects that can be adjusted to improve the user's experience even more. The first aspect is the visibility of the impact of the brainwaves on the matching process. The second aspect that could be improved is the amount of information given during the questions and the results. The last aspect is to enlarge the art database to a database that includes all different combinations of technique, theme, and colour-scene a minimum of three times.

Conclusions user test 2:

The second user test was done to investigate the influence of reading the question and explanation during the engagement level measurements. It can be concluded from the results that reading the question indeed influenced the measurements of the first test. Therefore, the engagement levels and the matching process becomes more accurate when using a different screen for the question/explanation and the artworks itself. The matching accuracy of this test was only 56%, which is lower than the first user test. However, this is probably due to the smaller user group that was tested.

Main conclusion:

In conclusion, the prototype that has been developed and tested proves that the concept for an art-visitor feedback system is feasible. The tests showed that is technically possible to realise a working prototype of such a system. The positive feedback from the users showed that the prototype added value to the users, as it improved their engagement and they learned more about the several art aspects. The adjustments that were implemented for user test 2 are good improvements of the quiz. However, many aspects still need to be improved to fully reach its maximum user experience and thereby improve the engagement and experience of a museum. These aspects are discussed in *Chapter 8*; Future work.

The Emotiv EPOC showed different aspects that are not useful for this concept. First of all, a second person is needed to correctly set up the headset. Besides that this is not convenient during the user tests, it may not be possible for a museum to have an extra employee/volunteer to help visitors with this all day. Furthermore, if the participant has long or thick hair, it is a lot of effort to correctly set up the Emotiv EPOC. And even if it is set up correctly, the Emotiv could lose contact quality during the measurements itself (see results user test 2). Therefore, the Emotiv EPOC is not the correct device to use for this concept.

Limitations:

Despite the clear results of the user test, the results cannot be used as harsh statements. This is due to multiple limitations of the tests, which include limitations on the equipment used, the participant group, the testing environment and the used art database. These limitations are described below.

The first limitation arises due to the equipment being used. Because the Muse 2 was not available at the University of Twente at the start of this research, the user tests were done with the Emotiv EPOC. Nonetheless, if the Muse 2 would have been available from the beginning, the results of the user tests could have been very different since the user experience differs a lot between the Emotiv EPOC and the Muse 2.

Secondly, the sample size of the user test is too small to draw well-founded conclusions. In total, 22 people participated in a user test (including the pilot test; *Section 4.4*), which is by far not enough participants to represent the population of the research sufficiently. Therefore, the results are not statistically proven and no harsh statements of the results can be made.

Additionally, the sample profile of the participants is limited. Only students participated because of time restrictions and CoVid-19 regulations. Because students do not represent all user groups that are going to museums, the sample profiles of the participants are a limitation to this research. Additionally, all participants are friends, housemates, or fellow students. Because they all are related to the researcher, the participants could be biased. Although the consent form clearly stated that all data is anonymous, participants could have been less strict or honest when filling in the survey not to hurt the researcher.

Another limitation to this research is the environment of the user tests, which was not inside a real museum. Most of the tests are done in a room at the University of Twente as museums were still closed due to Co-Vid 19 regulations. However, as stated by Brieber et al. [9] and Leder et al. [8] the environment has a lot of influence on the experience of art. Although the artworks are being displayed on a screen and not as a real painting, the environment could still influence the experience of the art and thereby of the quiz and survey.

The last limitation which influenced the user test is the size of the art database. The used database contained only 50 artworks, which resulted in combinations of art technique, theme and colour-scene that were not available in the dataset. This research did not investigate the user experiences of the prototype with a much larger database (minimum of all combinations three times), since there was no time to realise it. A large dataset was online available via an API, however, the laptop that is used during this research could not handle the dataset and the EEG signals at the same time. Therefore the database was a limitation for this research.

Despite the limitations, the survey results showed that the prototype is a feasible concept that is experienced as fun and intriguing. The results showed that the implementation of the EEG device is positively improving the experience even though the connections between electrodes and participants occasionally showed some problems. Almost all participants would recommend this system to others if it was placed in a real museum. For these reasons, the prototype proves to positively improve the experience of visitors when the final system is implemented inside a museum environment. The next step is to set up further research recommendations by the means of the conclusions of the user tests. These recommendations are stated in *Chapter 8.*

Chapter 7: Conclusion

This chapter concludes the research. The goal of the research was to find out how a BCI system can improve the engagement and experience of a museum visitor in combination with an interactive VidiNexus screen. The research is divided into three topics. Before the main conclusion is drawn, conclusions on the three topics are repeated from the extensive descriptions in previous sections.

The first topic is about the museum and art aspects that influence the experience of visitors in museums. By analysing the background research and the results of the interviews, it can be concluded that the amount of interaction inside a museum has a positive influence on the experience and engagement of visitors. Additionally, experiences can be improved when visitors know which aspects they can focus on when looking at art. In that way, visitors are able to concentrate better on the artwork, which could thereby improve the engagement and experience.

The second topic is about Brain-Computer interfaces and implementations inside museums. BCI is able to measure brainwaves, which after interpretation, can be used to give real-time and personal feedback to participants by measuring emotions or engagement levels. In that way, the otherwise hidden responses of visitors towards art can be used to improve their experience and engagement. EEG systems are chosen as BCI because these systems can be cheap, portable, and non-invasive [16], [24]. Two devices that are explored in more detail are the Muse headband and the Emotiv EPOC. Because the Muse headband was not able to connect to the laptop, the Emotiv EPOC was chosen.

The third topic consists of the ideation, specification, realisation and evaluation of the prototype. After the prototype of an art-visitor feedback system was created and realised, user tests were done to investigate the user experiences of the prototype. The Emotiv EPOC is used to measure engagement levels during the user tests. As expected, the Emotiv brought a lot of unwanted difficulties, such as long setup time and poor contact quality. Despite these difficulties, the experiences during the user tests were rated rather positively. Via the survey, observations, and engagement level measurements during the user tests, recommendations about the prototype, the user experience, and the interactions were formulated.

The findings of the three topics have been used to answer the main research question.

How can a Brain-Computer Interface system in combination with interactive screens improve the engagement and experience of museum visitors?

The engagement and experience of a museums visitor can be improved by using an art-visitor feedback system such as the prototype presented in this research. The user tests provided valuable feedback to support the statement. Participants described the quiz as fun and intriguing. Almost all participants would start the quiz if the start screen was displayed on the VidiNexus screen inside a museum and recommend this system to others afterward.

Furthermore, the prototype supports the conclusions about interaction, technical developments, and personalization derived from the background research. Namely, the prototype brings interaction into a museum which is, according to multiple sources [1], [2], [3] and interviews (*Section 2.5.1, 2.5.1 & 2.5.6*) one of the main aspects that positively improves a museum experience. Additionally, this prototype brings new technologies and societal developments towards museums, which according to Falk & Dierking [4] helps museums to remain relevant to visitors.

Another gap that was found in the background research is that museums lack instruments that provide entertainment, instructions, and visit personalisation [5]. This prototype fills that gap by providing an interactive quiz with a personalized outcome and thereby improving the experience and engagement inside museums. Furthermore, the prototype teaches visitors about different aspects of art. Actively knowing these aspects improves the experience by providing a framework of how visitors could look at art, which also improves the museum experience according to several interviews (*Sections 2.5.2, 2.5.3 and 2.5.6*).

Figure 34: The final system displayed on VidiNexus screen

Furthermore, this prototype has been developed with the interests and influences of all stakeholders in mind by means of the stakeholder analysis (*Section 3.1*). This ensures that the prototype is beneficial for all and does not favour nor exclude certain groups. Additionally, most of the design requirements (*Section 3.2)* and the user experience requirements (*Section 4.1.2*) are met through the design of this prototype.

Nonetheless, some limitations to certain aspects of this research could have influenced the research. Limitations of the user tests have been described in *Section 6.5.* The following limitations affected the entire research.

The Co-Vid 19 regulations formed a severe limitation to this research. Due to the regulations, it was not possible to work at the University. Most of the work needed to be done from home. This caused the researcher not interacting and reflecting with fellow students as much as during a normal project. Therefore, it was harder to come up with original ideas and it was easier to get stuck in your own bubble. Co-Vid 19 definitely slowed down the progress of the research, however, it is hard to state the exact influence of Co-Vid 19 on this research.

Also, the rather short duration limited this research. Because this research is done as a bachelor's graduation project, the duration of this research was only 10 weeks. Therefore, the research was on a strict time schedule. More literature research or more extensive user testing could have been done if more time would have been available. Additionally, more time to realize the prototype could ensure that the prototype would have been more advanced before testing. As a result, the prototype is only tested on a monitor connected to a laptop. Ultimately, the prototype should run and be displayed on a VidiNexus screen. Because of time limitations, it was impossible to include that within the scope of this research.

Despite these limitations, the prototype showed the validity of the primary conclusions about the positive contribution of improving the engagement and experience inside museums. To conclude, the prototype made during the third topic of this research is a good example of how the visitors' experience and engagement inside a museum can be improved.

Chapter 8: Future work

This section states recommendations for further research and improvements to enable the prototype to evolve to a commercial system. As stated in the conclusion (*Chapter 7*), the prototype is a good example of how the experience and engagement of visitors can be improved in museums. However, there is still a lot of room for improvements and further research.

Two main improvements to the prototype were found during the user tests and after inspecting the survey results. The first improvement that needs to be done is enlarging the size of the art database. For the tested prototype, the art database consisted only of 50 artworks. However, as the results of the user tests have shown, this is not enough to provide three existing artworks for every combination. Therefore tests with a larger database need to be done. If this system is used for a museum with less than 50 artworks, the matching algorithm or the classifications within the database should change to provide results with higher accuracy. Also, this needs to be tested before it could be implemented inside a real museum.

The second improvement that is necessary is altering the result screen to more specific information about the artworks for the specific visitor at hand. Although much information about the artworks was already displayed, participants during the user test stated they would like to see more background information about the matched artworks. Additionally, more information about why these specific artworks are matched is wanted. Therefore, the result screen should be altered to meet the needs of the users.

Besides the improvements that were found during the user tests, also more research into specific aspects could improve the prototype. Further research can be done into the following areas; the stakeholders, the museum environment, and the EEG device. Starting with the stakeholders, which is the focus point of the following two recommendations.

Until now, only a small portion of all stakeholders (For all stakeholders; *Section 3.3*) is included in the evaluation of the prototype. It is important to include other main stakeholders like museum employees and curators because they could have valuable insights about the system. These insights can be used to improve the prototype even more. Moreover, further research needs to be done to increase the usability of the prototype for other user groups. Currently, the user tests were focused on students between 18 and 28 years old. However, when this system is implemented inside a real museum, also other user groups are interacting with the system. Think of for example; the elderly, families, and children. Therefore, more research needs to be done to explore the interactions and experiences of the system with other user groups.

Because testing was done in a laboratory setting, some aspects of the quiz could not be determined. To be able to determine these aspects, testing inside a real museum environment should be conducted. These aspects are; the number of questions, the effect of the quiz on the entire museum visit, and the QR code/NFC connection. These aspects are explained below.

Firstly, it is difficult to define the number of questions of the quiz in a laboratory setting. This is because, in a real museum environment, certain elements come up that do not occur in a laboratory testing situation. Think for instance of participants waiting on each other to finish the quiz or people who take of a lot of time inspecting results. These elements have an influence on the number of questions and thereby the amount of time the quiz should take.

Secondly, the effect of the quiz on the entire museum visit should be explored, which can only be done in a real museum environment. It is important to study whether visitors really visit the artworks inside the museum or only say so in the survey of the user tests. Similarly, whether visitors take the information displayed on the result screen away via their phone, or again only say so in the survey. Additionally, research can be done on the effect of the art aspects explained in the quiz on the rest of the museum visit. Do visitors keep those aspects in mind or will they not think of those aspects again?

Thirdly, the quiz should be tested on a VidiNexus screen. This is because the current application is made for a laptop screen. However, on a big screen, the proportions of the artworks, text, or composition could be interpreted very differently. Preferably, the screen should stand in a museum environment, which ensures that the effect of the screen in the right environment can be explored simultaneously. Therefore, extra testing is needed on the VidiNexus screen in a museum.

The last two recommendations for future work are about the useability and accuracy of the EEG device. Firstly, the quiz currently only takes the engagement levels of the user into consideration for the matching process. However, other aspects could also be very interesting to classify artworks on, for example, interest levels, focus levels, or excitement levels. These aspects could be used in combination with or instead of engagement levels during the matching process and maybe even reach a higher accuracy when matching artworks. This is an aspect that should definitely be investigated during further researches.

Finally, more research needs to be done to explore possibilities in EEG devices. For this prototype, the user tests were done with the Emotiv EPOC. However, this device brought many unwanted difficulties, such as long setup times and insufficient contact quality between the electrodes and a participant. Therefore, this device is not suitable for a real museum environment. In the last weeks of the research, the Muse 2 became available, which is a more user-friendly device. This EEG device is able to connect with the quiz and could copy all functions of the Emotiv EPOC during the quiz. Therefore, extra research should be done to investigate the user experiences and user interactions further with the Muse device.

The prototype art-visitor feedback system developed in this research provides enough indications of its potential for improving the visitors’ experience and engagement inside a museum to justify further research and development.

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Appendices

Appendix A: Expert interview protocol and questions

1 Read the information brochure and sign the consent form
2 General introduction about the project
3 Introduction about ourselves
4 Introduction questions to the interviewee:
- Can you tell something about yourself?
- What is your role inside the museum?
- What is your favourite part about it?
- How long are you already inside the museum business?
- What is your favourite project within this museum?

5 Question about the museum and user experiences:
- What are the target groups for this museum?
- What technologies are already used inside this museum?
- What technologies would you want to implement in the museum?
- Do you think technology is able to improve the user experience?
- What are, according to you, the most important innovations inside a museum to improve the user experience?
- What is your opinion about connecting art and technology?

6 General introduction about VidiNexus
7 Questions about the VidiNexus screen
- The VidiNexus screen is already used in one of the exhibitions, can you tell a little about it?
- Where was the screen placed?
- How was it used?
- What was the experience that visitors have with the VidiNexus screen?
- For what goal would you like to use an interactive screen?
- Where would you place such a screen?

8 Questions about the use of sensors
- Do you already implement sensors inside your museum?
- Do you think sensors could improve the experience in any way?
- Would you like to experiment with sensors?

9 General questions
- Do you have any suggestions for us?
- Do you still have something you would like to add?
- Are we able to do user-tests inside the museum?

10 Closing and thanking the interviewee

Appendix B: Visitor interview protocol and questions

1. Read the information brochure and sign the consent form
2. Demographic questions
    a. How old are you?
    b. How often do you go to museums?
    c. Which kind of museums do you like the most?
    d. Do you have an 'Museumkaart' ?
    e. On a scale from 1 to 10, how interested are you in art?
3. General museum questions
    a. What does a standard museum visit look like for you?
    b. Do you read all the given information on the sides of art-works?
    c. What was the most interesting experience you had inside a museum?
    d. How can a museum experience be improved for you?
    e. Can you think of aspects which could change that will make you go to museums more often?
4. Technology inside museums questions
    a. What is your experience with technology inside a museum?
    b. How can technology play a role in improving the museum experience for you?
    c. What do you think about sensors inside a museum?
    d. Would you feel comfortable with your moves being measured?
    e. Would you feel comfortable with your brainwaves being measured?
    f. Would you like to receive personal information during your visit?
    g. In what way would you like to receive this information?
    h. Would personalised information make you more engaged inside a museum?
5. General questions
    a. Do you have any suggestions?
    b. Do you still have something you would like to add to the conversation?
6. Closing and thanking the interviewee

Appendix C: Information brochure and informed consent; Interviews

Information Brochure

This research is conducted to get insight into curatorial practice and technology in different types of museums. The interview will be used to develop new features for a product that is made by the company VidiNexus.

There are no adverse effects for the participants of this interview because the interview will be about their experience with technologies inside of museum environments. There will be no questions about sensitive or personal information.

Participants of the interview will receive no remuneration. Participants need to be 18 years or older. There are no further limitations for participants. The information will be gathered through semi-structured interviews. The interviews will be recorded, transcribed and stored on an encrypted usb drive. The recordings and transcriptions will be deleted before the first of September of 2021. The transcribed data will be made anonymous, and thereby anonymously used in the research rapport. The recordings and transcriptions will not be shared with third parties, including our client VidiNexus. The participant may discontinue the interview at any moment, which will have no negative impact for the participant. After a participant withdraws, the data that is already gathered will be removed completely. The participant also has the right to withdraw from the research within 24 hours after the interview.

For objections regarding the design or execution of the research, you can also contact the secretary of the Ethical Committee of the faculty Behavioural, Management and Social Sciences at the University of Twente via ethicscommittee-bms@utwente.nl.

Name researcher 1: Simone Luiten
Address researcher: Leijdsweg 40, Enschede
Telephone number: 0031 6 25020553
E-mail address: s.luiten@student.utwente.nl

Name researcher 2: Leon Groothaar
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Telephone number: 0631387339
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Name researcher 3: Marissa Mul
Address researcher: Deurningerstraat 25-1, Enschede
Telephone number: 0617785092
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Project coordinator: Department Human Media Interaction.
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Tel: +31 (0)53 489
Email: ethicscommittee-bms@utwente.nl

Project supervisor: DR. M. Poel
Email: m.poel@utwente.nl
Tel: +31534893920

Informed consent

'I hereby declare that I have been informed in a manner which is clear to me about the nature and method of the research as described in the aforementioned information brochure. My questions have been answered to my satisfaction. I agree of my own free will to participate in this research. I reserve the right to withdraw this consent without the need to give any reason and I am aware that I may withdraw from the experiment at any time. If my research results are to be used in scientific publications or made public in any other manner, then they will be

made completely anonymous. My personal data will not be disclosed to third parties without my express permission. If I request further information about the research, now or in the future, I may contact Simone Luiten.

If you have any complaints about this research, please direct them to the secretary of the Ethics Committee of the Faculty of Electrical Engineering, Mathematics and Computer Science at the University of Twente, P.O. Box 217, 7500 AE Enschede (NL), email: ethics-comm-ewi@utwente.nl).

Signed in duplicate:

....	....
Name subject	*Signature*

I have provided explanatory notes about the research. I declare myself willing to answer to the best of my ability any questions which may still arise about the research.'

....	....
Name researcher	*Signature*

Name researcher 1: Simone Luiten
Address researcher: Leijdsweg 40, Enschede
Telephone number: 0031 6 25020553
E-mail address: s.luiten@student.utwente.nl

Name researcher 2: Leon Groothaar
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Appendix D: Brainstorm table

How to inform visitors about the system at the entrance of the museum?

- With the VidiNexus screen
  o Text
  o Video
  o Pictures and text
- With big signs on the walls
- Projector on the wall
  o Text
  o Video
- Small paper handouts
- A person explaining everything real life

How to reach/inform people during visit?

- Paper handouts
- Audio tour
  o Personalized
  o General
  o Sensor connected
  o Location based → Wi-Fi, Bluetooth, pressure sensors
- Paper handouts
- Little book
- Signs on the walls
- Screens → VidiNexus
- Personal guide
- Pictures
- Text on the floor
- Special glasses
- Video

How to make sure visitors take enough time for each artwork?

- Clock ticking
  o Digital
  o Analogue
- Real time audio tour (when it is done talking, the visitor knows it can walk further)
- Lights displaying time
  o In the ground
  o On the wall
  o On a gadget people carry with
    ▪ Watch
- Stopwatch
- Vibrations
- Sounds

How to connect the art inside a museum to nature and rhythms outside a museum?
- Examples - Connecting visitors with each other - Videos - Sounds

- Music
What to measure during the visit?

- Stress level → Empatica
- Excitement → Empatica
- Heart beat → Empatica and Muse 2
- Emotions → EEG (Brainwaves)
    o Muse
    o Emotiv
- Facial recognition
- Skin conductance
- Eye movement → Tobi Glasses

How do the visitors receive feedback on their performance?

- Real time:
    o Lights
    o Audio
    o Text
    o Scale
    o VidiNexus screen
- At the end of the visit/system:
    o VidiNexus screen
    o Lights
    o On their phones
    o Via email
    o NFC connection
    o Bluetooth connection

What feedback do the visitors receive?
- Extra information on the most excitement artworks - Extra information on how to connect art with the outside environment - A top 5 of most exciting artworks - A top 5 of the most neutral artworks - Feedback on how well it went to postpone emotions - Facts about specific parts of the artwork - Tips for other museums that fit the most exiting artworks - At which artworks postponing emotions worked best
How does the system know when to collect and process data?
- Buttons - RFID tag - Camera sensor - Sensor in the ground - Eye tracking
How does the system know at which painting you are looking?
- Eye tracking - Wifi beacons
What kind of information can be given about an artwork?
- Artist - Art process - Art style - History - Place where the art is made - The places the art has been

Appendix E: Mind map: Interactive application

Appendix F: Pilot test questions

Start-screen questions:

- Does the infographic look appealing to you?
- How well do you understand the system after reading the infographic?
- If you see this start screen on the VidiNexus screen at the entrance of a museum, would you walk towards it?
- Are there aspects you would change?

Quiz questions:

- Do the question screens look appealing to you?
- Are the questions clear?
- Is there an art aspect you would like to have a question about?
- Do you feel that you learned something about the aspects (in the questions) of art?

Result-screen questions:

- Are the results clear?
- Does the result screen look appealing to you?
- Do you like the matched artworks?
- What extra information would you like to see on the result screen?
- If this quiz would be in a real museum, would you visit the matched artworks?
- If this quiz would be in a real museum, would you feel more connected to the matched artworks?

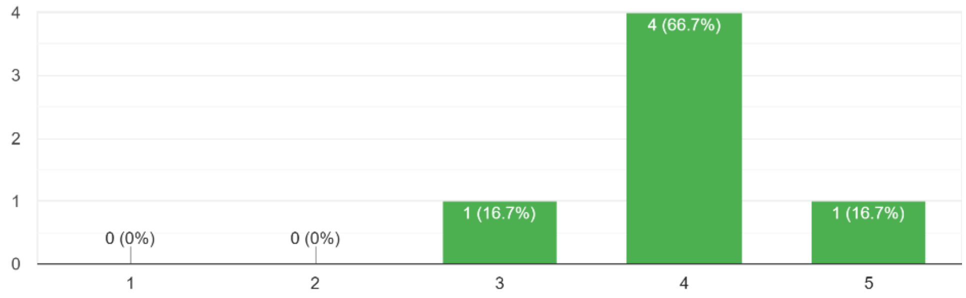
General questions:

- Did you like the quiz?
- Do you have any remarks?
- Do you have any recommendations?

Appendix G: Results survey: pilot test

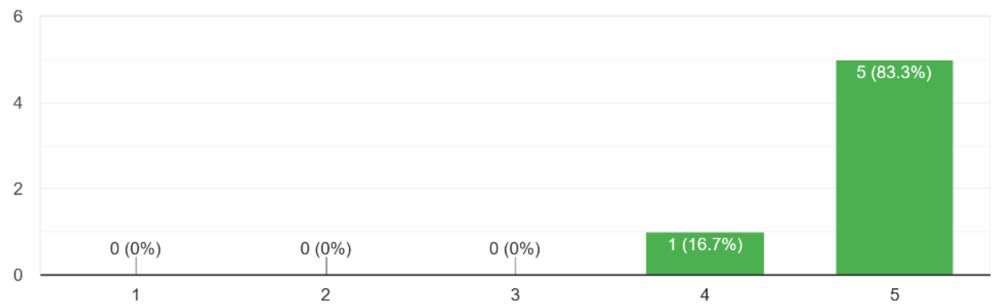
Does the infographic look appealing to you?

6 responses



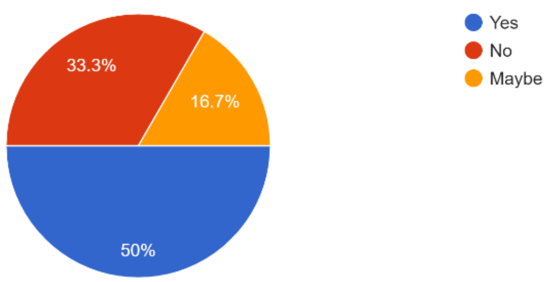
How well do you understand the system after reading the infographic?

6 responses



If you see this screen on a big (VidiNexus) screen at the entrance of an art museum, would you walk towards it?

6 responses



Are there aspects you would change of the infographic or the start screen itself?

6 responses

Yes:
The icons do not match, the text on the infographic very well.
In general I think there is too much text.

I would add a captivating first screen (sort of like a screen saver, with a big title and cool artworks to draw more attention to the vidinexus screen, so that it is clear that there is a cool interactive application to play.)

NOPES

Make a slideshow with this pic as one image and another image with big letters saying something like "Match Art with Brainwaves".

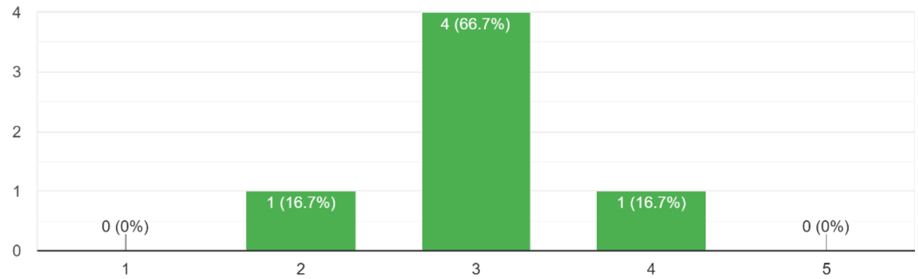
The Font, and feather the image of the female with the MUSE.

Nothing that I can think of

Een groot start hier uw ervaring logo zou wel heel nice zijn, of zou me in ieder geval motiveren om er heen te lopen.

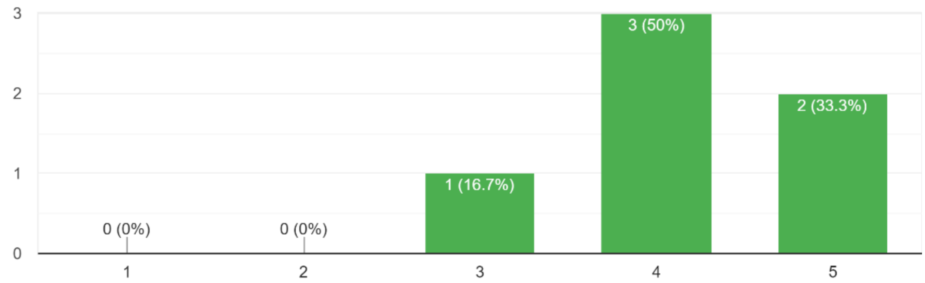
Do the question screens look appealing to you?

6 responses



Are the questions clear?

6 responses



Is there another art aspect you would like to have a question about?

3 responses

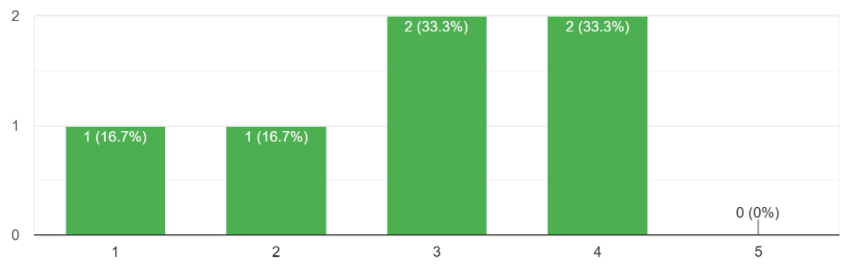
For oil on canvas, it would be nice to have differences in technique: (like classic or pop art, impressionism).)

Time Period

Een vraag over wat voor soort kunst je leukt vind kan wel handig zijn: dus modern of juist oud.

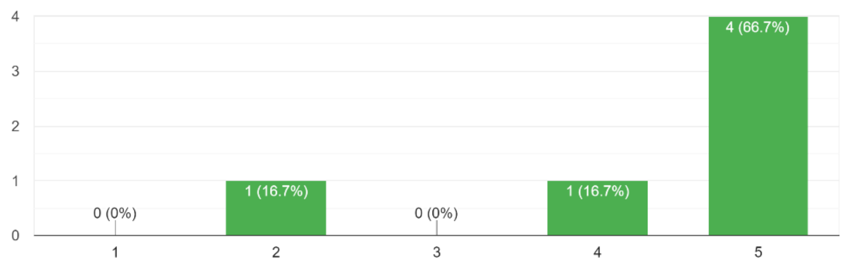
Do you feel like you learned something about the art aspects of the questions?

6 responses



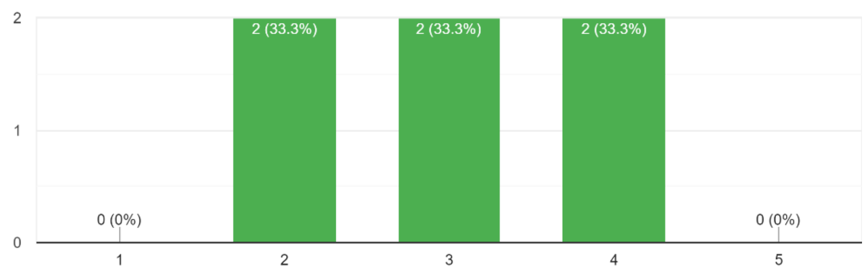
Are the results clear?

6 responses

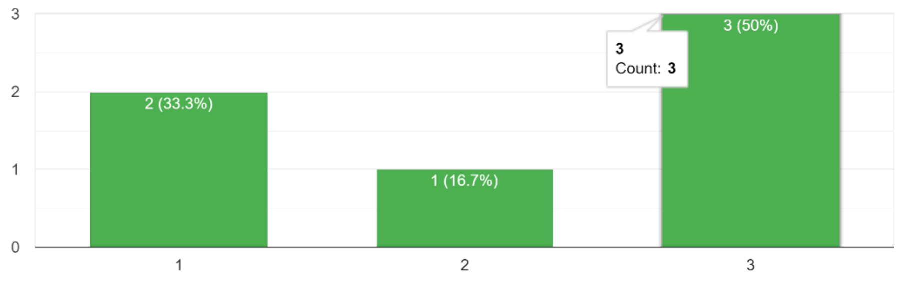


Does the result screen look appealing to you?

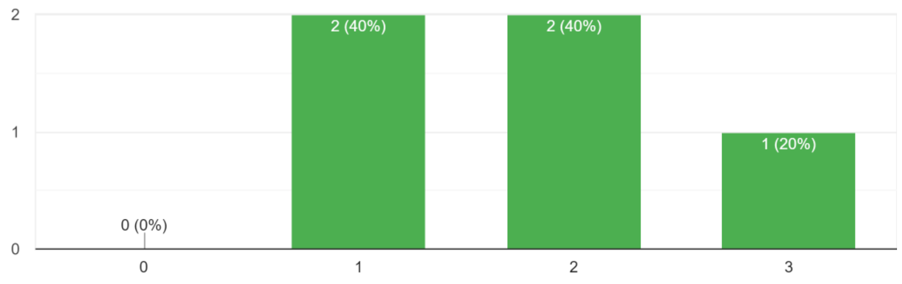
6 responses



How many matched artworks did you have?
6 responses



How many matched artworks did you like?
5 responses



What extra information would you like to see on the result screen?

4 responses

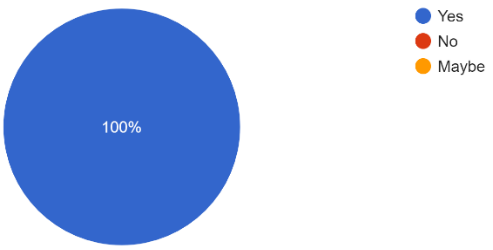
It would be nice to know why these paintings are matched to me.

Background information of the artwork. Like: What was the motivation behind this work?

Which of the art aspects the artworks correspond with

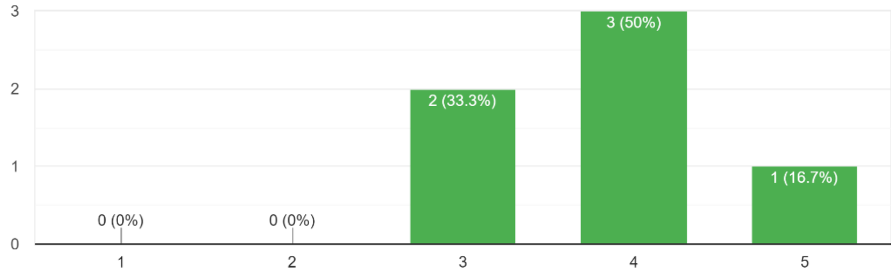
where the artwork is located inside of the museum

If this quiz would be in a real museum, would you visit the matched artworks?
6 responses



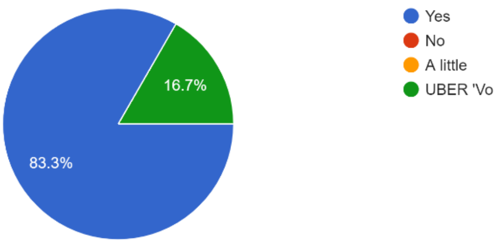
If this quiz would be in a real museum, would you feel more connected to the artworks? (compared with before?)

6 responses



Did you like the quiz?

6 responses



Do you have any recommendations or remarks about the system?

4 responses

Yeah it would be nice to click with the mouse. And add a eyecatching start screen.

meer vragen voor keuze kunst

It is very clear, but could look a bit more appealing/ professional design.

would like to see it on a real vidinexus system.

Appendix H: Python code link

The python code can be found via the following link:
https://github.com/Simoneluiten/Graduation-Project-VidiNexus

Appendix I: Art Database

The art database can be found using the following link:
https://docs.google.com/spreadsheets/d/1rrVkQujtBee4BXy6DKoIrWTvwFti3igxrQhz10s25tY/edit?usp=sharing

Appendix J: Information brochure and consent form; User testing

Information brochure

This research is conducted to get insight into user experience and the human-computer interactions of the system. The research procedure will consist of two steps. The first step is to interact with the system by participating in an interactive quiz. During the quiz, the participant will wear an EEG device on the head. This device is able to measure the brainwaves of participants and is thereby able to detect engagement levels. The device is easily put on and off. The interactive quiz will match the participant to certain artworks dependent on the answers they give and the brainwaves that are measured. The second step in this research is to fill out an evaluation form. This form will ask the participant about the user experience, interactions and improvements of the quiz.

There are no adverse effects for the participants of this research. The research will be fully focussed on improving the user interactions and experiences. There will be no questions asked about sensitive or personal information during the quiz or evaluation form.

Participants of the research will receive no remuneration. Participants need to be 18 years or older. There are no further limitations for participants. The data of the EEG device is deleted immediately after the results of the quiz are shown. This data will not be analysed for any medical conditions, which will make accidental medical discoveries not possible. The information of the evaluation form will be used to improve the system. After the information is put anonymously in the report, it will be deleted before the last of July 2021. The information will not be shared with third parties.

The participant may discontinue the interview at any moment, which will have no negative impact for the participant. After a participant withdraws, the data that is already gathered will be removed completely. The participant also has the right to withdraw from the research within 24 hours after the interview.

For objections regarding the design or execution of the research, you can also contact the secretary of the Ethical Committee of the faculty Behavioural, Management and Social Sciences at the University of Twente via ethicscommittee-bms@utwente.nl. If you have specific questions about the handling of personal data, you can contact the Functionary Data Protection of the University of Twente, by mailing dpo@utwente.nl. Finally, you have the right of a request for insight, modification, removing or altering of your personal data. This can be requested through the research manager.

Name researcher: Simone Luiten
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Project supervisor: DR. M. Poel
Email: m.poel@utwente.nl
Tel: +31534893920

Informed consent

'I hereby declare that I have been informed in a manner which is clear to me about the nature and method of the research as described in the aforementioned information brochure. My questions have been answered to my satisfaction. I agree of my own free will to participate in this research. I reserve the right to withdraw this consent without the need to give any reason and I am aware that I may withdraw from the experiment at any time. If my research results are to be used in scientific publications or made public in any other manner, then they will be made completely anonymous. My personal data will not be disclosed to third parties without my express permission. If I request further information about the research, now or in the future, I may contact Simone Luiten.'

If you have any complaints about this research, please direct them to the secretary of the Ethics Committee of the Faculty of Electrical Engineering, Mathematics and Computer Science at the University of Twente, P.O. Box 217, 7500 AE Enschede (NL), email: ethics-comm-ewi@utwente.nl).

Name subject: **Signature:**

'I have provided explanatory notes about the research. I declare myself willing to answer to the best of my ability and questions which may still arise about the research'

Name researcher: Simone Luiten **Signature:**

Name researcher: Simone Luiten
Address researcher: Leijdsweg 40, Enschede
Telephone number: +31 6 25020553
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Appendix K: Survey questions user test 1

Questions survey:

- Start screen:
    - Did the start screen make you curious about the system?
    - Would you walk towards the VidiNexus screen if it displayed this start screen?
    - Any comments/remarks?
- Menu screen:
    - Does the infographic look appealing?
    - Did you understand the system after reading the infographic?
    - Were you excited to start the quiz after reading the infographic?
    - Any comments/remarks?
- Question screens:
    - Did you like the art aspects that the questions were about?
    - Do you feel like you learned something about different art aspects from the questions? If yes, what did you learn?
    - When looking at other artworks, will you focus on some of the art aspects you learned?
    - What did you think of the 30 second waiting time?
    - Any comments/remarks?
- Result screen:
    - How many matched artworks did you have?
    - How many matched artworks did you like?
    - Do you feel more connected with the matched artworks after participating in this quiz? (in comparison with before?)
    - Would you go visit the artworks in the museum?
    - Would you want to have more information about the matched artworks? For example by taking the extra information away via an QR code/NFC connection?
    - Any comments/remarks?

  Interaction/EEG device questions:
    - Are the interactions during the quiz natural?
    - Did you like the aspect that your brainwaves were part of the matching process?
    - Do you feel that that the EEG device improves the whole experience of the quiz?
    - Would you like to know more about your brainwaves and engagement levels?
    - Any questions/remarks about the EEG system?

  General quiz questions:
    - Did you like participating in the quiz?
    - How would you describe the experience of the quiz?
    - Would you recommend this quiz to others?
    - Any remarks/recommendations for the system in general?
- Thanks for participating!

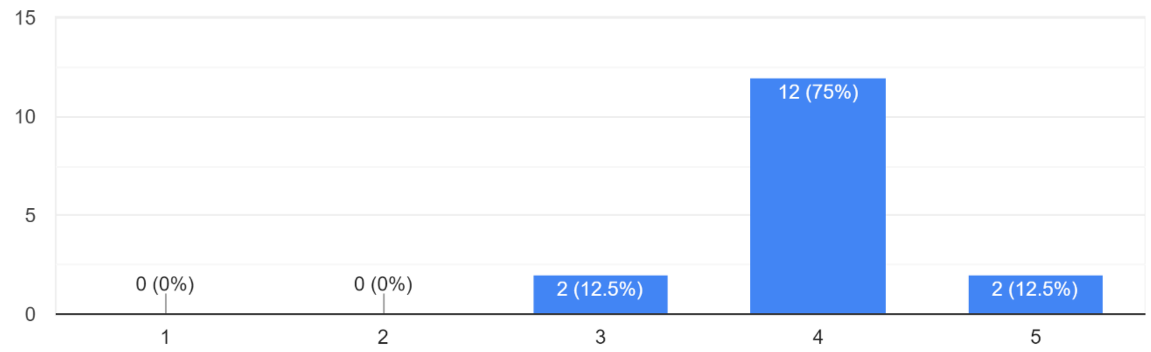
Appendix L: Observation table user tests

The observations made during the User test 1 can be found via the following link: https://docs.google.com/spreadsheets/d/12DUn2df4QRkfstwpjgRCI7v3kJd6-_zXBvu1Oqfiras/edit?usp=sharing

Appendix M : Results survey: user test 1

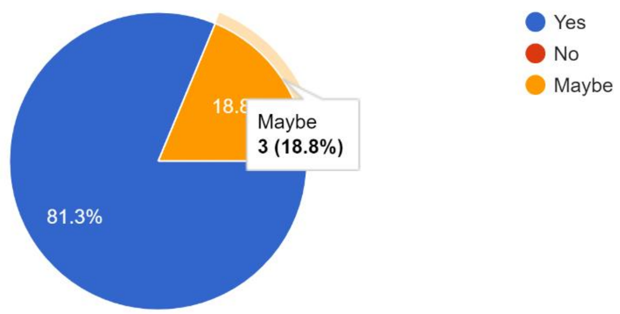
Did the start screen make you curious about the system?

16 responses



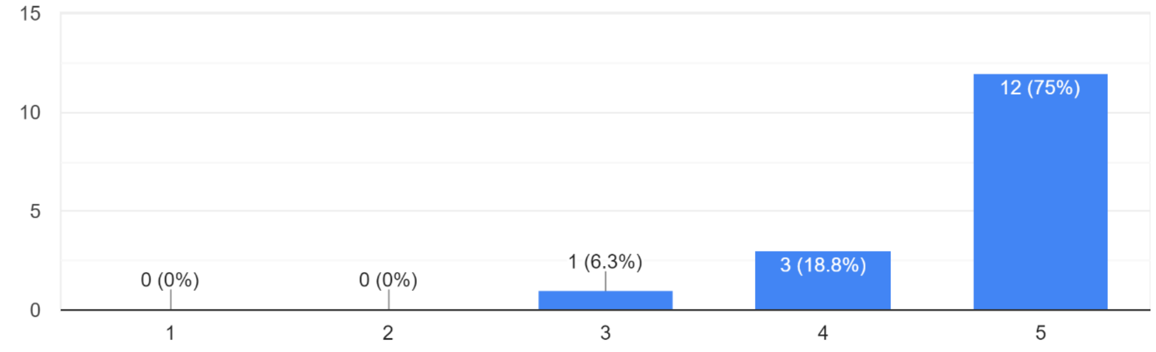
Would you walk towards a big interactive screen if it displayed this start screen?

16 responses



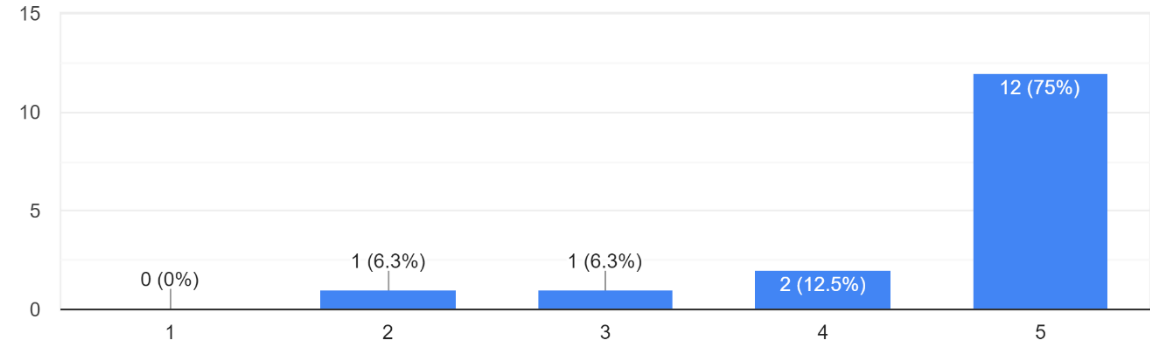
Does the infographic look appealing?

16 responses



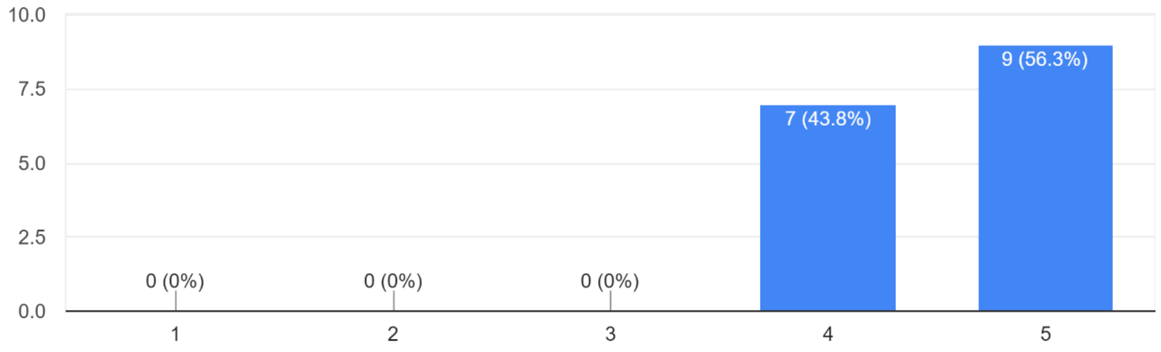
Did you understand how the quiz works after reading the infographic?

16 responses



Were you excited to start the quiz after reading the infographic?

16 responses

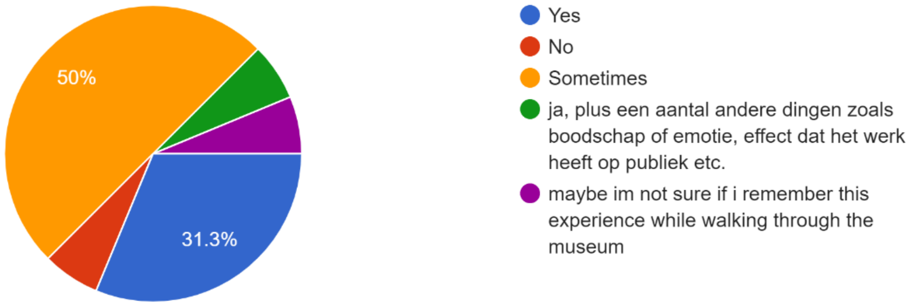


Did you like the art aspects that the questions were about? (technique, theme and color scene)

16 responses

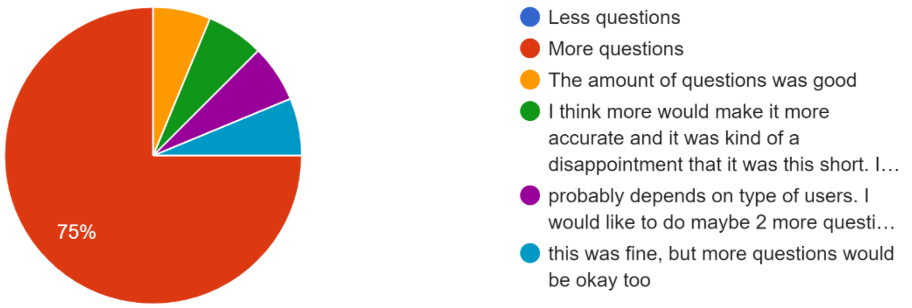
When looking at other artworks, will you focus on some of the art aspects you learned during the quiz? (Technique, Theme, Color scene)

16 responses

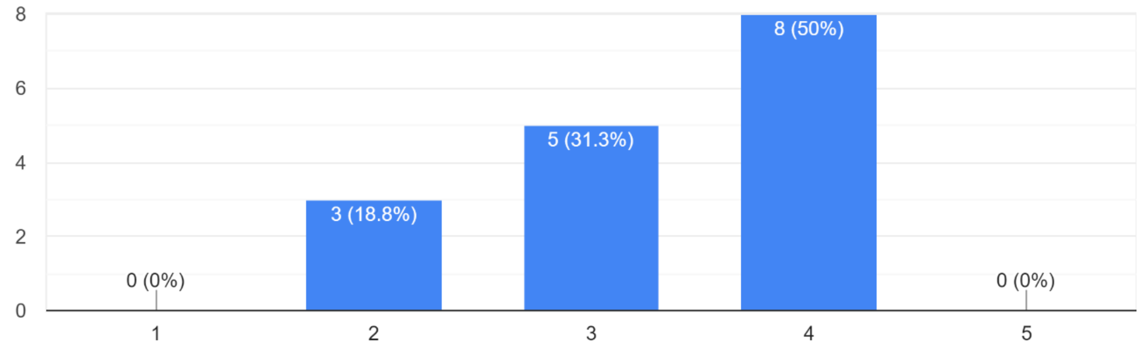


What did you think of the amount of questions (3)? Would you rather have more or less questions?

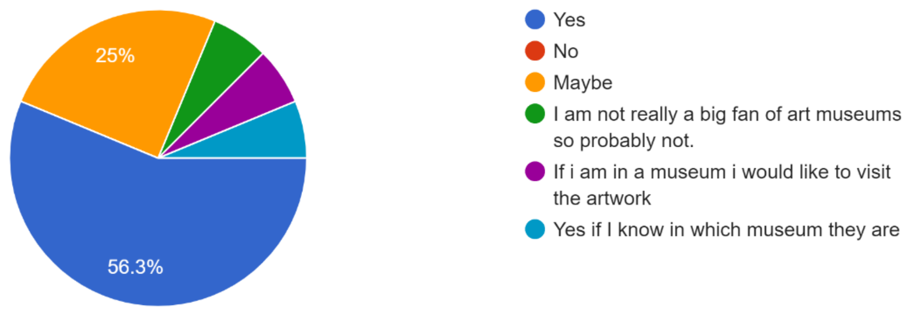
16 responses



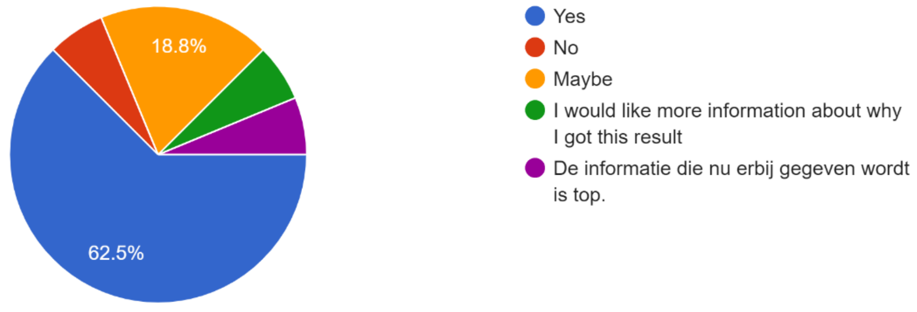
Do you feel more connected to the matched artworks after participating in this quiz? (in comparison with before?)
16 responses



Would you go visit the artworks in the museum?
16 responses

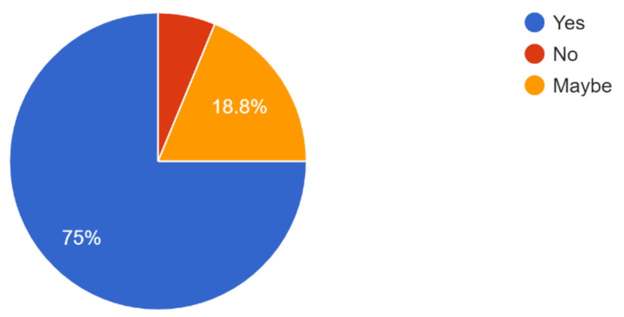


Would you like to have more information about the matched artworks?
16 responses



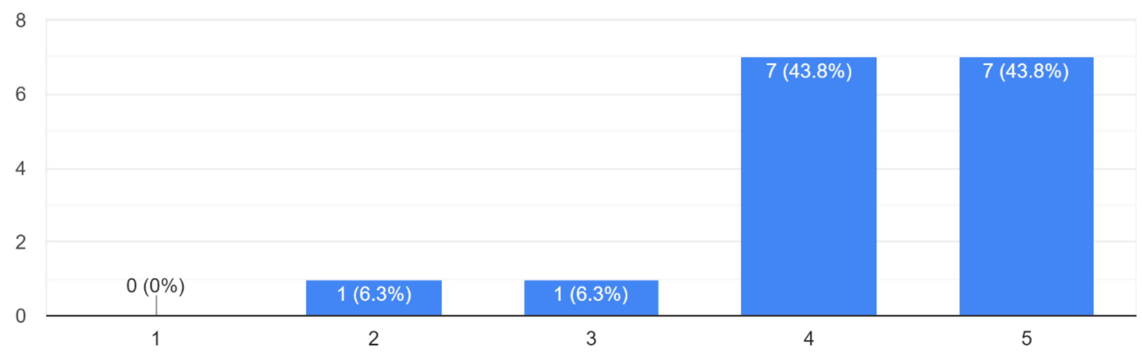
Would you take the information (matched artworks) away via an QR code or NFC connection?

16 responses



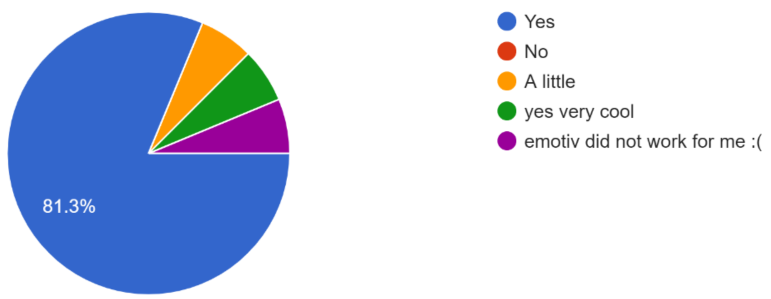
Did the interactions during the quiz feel natural?

16 responses



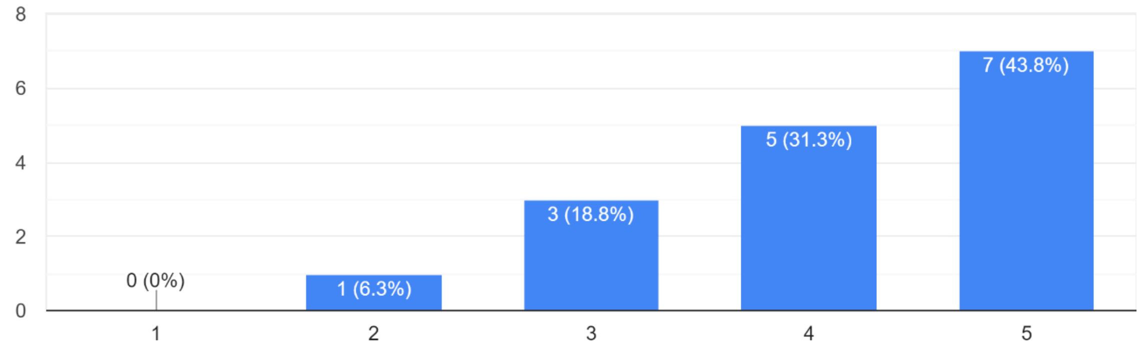
Did you like the aspect that your brainwaves were part of the matching process?

16 responses



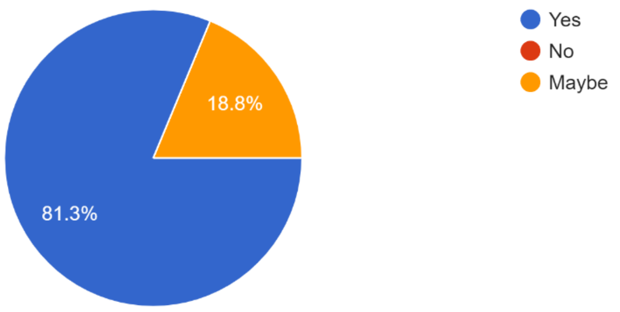
Do you feel that the EEG device improves the whole experience of the quiz? In comparison with without the EEG device?

16 responses



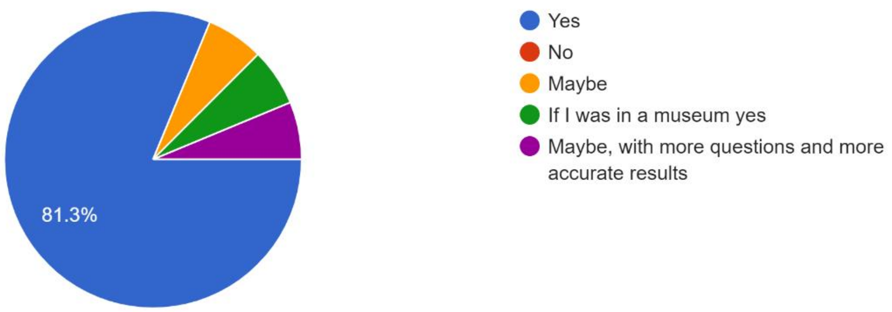
Would you like to know more about your brainwaves and engagement levels in general?

16 responses



Would you recommend this quiz to others?

16 responses



Appendix N: Survey questions user test 2

Questions survey:

- Were you able to concentrate the whole 30 seconds?
- How was your concentration level throughout a quiz question?
- Which question did you find the most interesting?
- How many matched artworks did you have?
- How many matched artworks did you like?
- Would you go visit the artwork inside a museum?
- Did the interaction during the quiz feel natural?
- Any remarks/comments?