New Interactive Interface Design for STEM Museums: A Case Study in VR Immersive Technology

Pornphan Phichai

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School of Computing Science
College of Science and Engineering
University of Glasgow

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Abstract

Novel technologies are used to develop new museum exhibits, aiming to attract visitors' attention. However, using new technology is not always successful, perhaps because the design of a new exhibit was inappropriate, or users were unfamiliar with interacting with a new device. As a result, choosing alternative technology to create a unique interactive display is critical. The results of using technology best practices enable the designer to help reduce failures.

This research uses virtual reality (VR) immersive technology as a case study to explore how to design a new interactive exhibit in science, technology, engineering and mathematics (STEM) museums. VR has seen increased use in Thailand museums, but people are unfamiliar with it, and few use it daily. It had problems with health concerns such as motion sickness, and the virtual reality head-mounted display (VR HMD) restricts social interaction, which is essential for museum visitors. This research focuses on improving how VR is deployed in STEM museums by proposing a framework for designing a new VR exhibit that supports social interaction. The research question is, how do we create a new interactive display using VR immersive technology while supporting visitor social interaction? The investigation uses mixed methods to construct the proposed framework, including a theoretical review, museum observational study, and experimental study. The in-the-wild study and workshop were conducted to evaluate the proposed framework.

The suggested framework provides guidelines for designing a new VR exhibit. The component of a framework has two main parts. The first part is considering factors for checking whether VR technology suit for creating a new exhibit. The second part is essential components for designing a new VR exhibit includes Content Design, Action Design, Social Interaction Design, System Design, and Safety and Health.

Various kinds of studies were conducted to answer the research question. First, a museum observational study led to an understanding of the characteristics of interactive exhibits in STEM museums, the patterns of social interaction, the range of immersive technology that museums use and the practice of using VR technology in STEM museums. Next, the alternative design for an interactive exhibit study investigates the effect on the user experience of tangible, gesture and VR technologies. It determines the factors that make the user experience different and suggests six aspects to consider when choosing technology.

Third, social interaction design in VR for museum study explores methods to connect players; single player, symmetric connection (VR HMD and VR HMD) and asymmetric connection (VR HMD and PC), to provide social interaction while playing the VR exhibit and investigates social features and social mechanics for visitors to communicate and exchange knowledge. It found that the symmetric connection provides better social interaction than others. However, the asymmetric link is also a way for visitors to exchange knowledge. The study recommends using mixed symmetric and asymmetric connections when deploying VR exhibits in a museum. This was confirmed by the in-the-wild research and validated the framework that indicated it helped staff manage the VR exhibit and provided a co-presence and co-player experience. Fourth, the content design of a display in the virtual environment study examines the effect of design content between 2D and 3D on visitors' learning and memory. It showed that content design with 2D and 3D did not influence visitors to gain knowledge and remember the exhibit's story. However, the 3D view offers more immersion and emotion than the 2D view. The research proposes using 3D when designing content to evoke a player's emotion; designing content for a VR exhibit should deliver experience rather than text-based learning. Furthermore, the feedback on the qualitative results of each study provided insight into the design user experience.

Evaluation of the proposed framework is the last part of this research. A study in the wild was conducted to validate the proposed framework in museums. Two VR exhibits were adjusted with features that matched the proposed framework's suggested components and were deployed in the museum to gather visitors' feedback. It received positive feedback from the visitors, and visitors approved of using VR technology in the museum. The results of user feedback from a workshop to evaluate the helpfulness of the framework showed that the framework's components are appropriate, and the framework is practical when designing a new VR exhibit, particularly for people unfamiliar with VR technology. In addition, the proposed framework of this research may be applied to study emerging technology to create a novel exhibit.

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Author's Declaration

The research presented in this thesis is entirely the author's own work. Research in this thesis has been published at the following venues, using only the parts of the paper that is directly attributable to the author:

• The research in Chapter 5 has been published at iLRN 2021: Pornphan Phichai, Julie Williamson, Matthew Barr. "Alternative Design for An Interactive Exhibit Learning In Museums: How Does User Experience Differ Across Different Technologies-VR, Tangible, And Gesture." Proceedings of the 7th International Conference of the Immersive Learning Research Network. IEEE, 2021, pp. 1-8.

• The proposed framework was presented in the workshop to evaluate the framework with the National Science Museum Thailand, the Shanghai Science & Technology Museum, National Science and Technology Taiwan, and The National Museum of Emerging Science and Innovation Japan. April 2022.

• The VR exhibits in Chapter 6 and Chapter 7 was displayed inside the museums of the National Science Museum Thailand for evaluated with the museum's visitors. March-April 2022.

All studies have been approved by the College of Science and Engineering Ethics Committee Chapter 4 (Application No. 300200046), Chapter 5 (Application No. 300180276), Chapter 6 (Application No. 30020009), Chapter 7 (Application No. 300210008), Chapter 8 and Chapter 9 (Application No. 300210146).

Definitions/Abbreviations

AR: Augmented Reality

D1: Design One

D2: Design Two

D3: Design Three

DOF: Degree Of Freedom

XR: Extended Reality

GLOs: Generic Learning Outcomes

GUI: Graphic User Interface

HMD: Head Mounted Displays

HCI: Human-Computer Interaction

IPQ: I Group Presence Questionnaire

IQR: Interquartile Range

LCL: Learning Combination Lock

M: Mean value

MR: Mixed Reality

R1: Role player One

R2: Role player Two

RQ: Research question

STEM: Science, Technology, Engineering, Mathematics

SD: Standard Deviation

TTF: Task and Technology Fit

3D: Three-dimensional

2D: Two-dimensional

UEQ: User Experience Questionnaire

VB: Virtual Body

VE: Virtual Environments

VR: Virtual Reality

VR HMD: Virtual Reality Head Mounted Displays

Z: Z-score, also called a standard score

α: Alpha, the significance level

***p*:** Probability

$\chi 2$: Chi-square

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Chapter 1 Introduction

1.1 Motivation

Science museums and science centres have a mission to engage people in their community to adopt and adapt science in their daily life. The exhibits are one of the main parts that museums use to convey messages and deliver knowledge to visitors. Many exhibits have been developed over the years to engage visitors to learn more about STEM (Science, Technology, Engineering, Mathematics), especially using novel technology to attract visitors' interest to visit their museum [5] [188]. The new generation of museums focuses on using interactive and innovative exhibitions to engage and connecting their visitors [188]. Many failures are found when using new technology to create a new interactive exhibit. For example, the new technology may prevent visitors from accessing the content of the exhibit due to unfamiliarity with interacting with the exhibit using a new device, or through interaction design inappropriate for the use of the new technology, or because the academic content did not suit for convey the message with the new technology, etc. [137]. So, best practice for using technology must be followed to reduce failure.

Immersive technology has been introduced in museums for a long time, and the oldest example is the diorama which usually shows animal habitats [21]. Designing an exhibit with immersive features makes it more memorable than other approaches [68]. Gilbert [68] describes why museums might include immersive exhibits in museums. She stated three main major reasons. First, to compete with other institutions a leisure-time activity. Second, to attract attention and offer a memorable experience. And third, to deliver the content of the exhibit effectively. VR is a novel technology and is used increasingly in an education context [37]. VR applications can be used for simulation, training, accessing resources that are limited, and distance learning [37]. And another positive aspect of VR is reduced cost to travel and reduced impact on the physical natural world, while it still has the potential to offer the experience to users to feel connected with nature [202].

Even though VR has appeared in museums for a long time, fewer museums adopt and apply them as exhibits for many reasons such as motion sickness, weight of equipment, cost of device, etc. [36, 102]. Currently, the quality of VR head mounted displays (HMD) has improved, and the cost per device decreased, so many museums tend to employ VR [38].

Moreover, the effect of using VR in museums has been widely explored in terms of how it benefits museum visitors and provides entertainment and learning opportunities for visitors to experience [191] [119]. Meanwhile, museums in Thailand are beginning to adopt VR technology to create interactives [188].

The interactive exhibit is one kind of learning media, so the design of the exhibit's content is crucial. Much research was interested in investigating the efficiency between 2D and 3D media for learning [195] [196] [42] [104]. Shibata et al. [195], found viewing content with 3D better facilitates learning and can see more detail than 2D. Shu et al. [196] found that 3D view using VR HMD offers a sense of presence and immersion to players than 2D view using desktop VR. And de Boer et al. [42], students achieve in learning with 3D than 2D. On the other hand, Kim and Hong [104] found that 2D offer more effective and intuitive communication information than 3D. Considering VR technology offers to display 3D content and also enables to display 2D content in the virtual environment. So, design content for a VR exhibit should consider between 2D and 3D.

However, using VR HMD in public spaces raises many issues. The main issue that museums should be concerned about is that using eyewear technology like VR HMD does not facilitate social interaction between visitors. It reduces visitors' communication, sharing their experience and their expression. In addition, children may need their parents to explain the scientific content of the exhibit. While social interaction is essential in education, it is not emphasised in VR exhibit development because implementing multiuser is still costly [99]. So, this study intends to address the issues described above, in order to provide a framework for STEM museums to create new exhibits using VR and provide social interaction between visitors.

1.2 Thesis Statement

This research focuses on improving how VR is deployed in STEM museums by proposing a framework for facilitating conversations between developers and exhibition designers to create a VR exhibit. It is the bridge in collaboration design between technologists and non-technologists to design a new VR exhibit. The proposed framework incorporates content design, interaction design, social interaction design, system design, health and safety. *Content design* comprises the factors for designing a learning experience, changing techno-scientific content into an experience. *Action design* is the suggestion feature for designing how visitors interact with a VR exhibit. *Social interaction* provides guidelines to support designing social interaction between visitors for the VR exhibit. *System design* comprises the essential features for designing a system for each VR exhibit in a STEM museum. Finally, *safety and health* are the suggested factors that make visitors safe when using a VR exhibit.

1.3 Research Questions

The main research question is how we can create a new interactive exhibit with consideration for using VR immersive technology while supporting social interaction between visitors. This larger question may be broken down into five sub questions, as follows.

Table 1.1 Research question and corresponding study.

RQs	Corresponding study
RQ1: how does the choice of technology used to create an exhibit affect visitors' experience?	Study one
RQ2: what are the factors that should be considered when choosing technology?	Study one
RQ3: what kind of activity will create social interaction in VR?	Study two
RQ4: what kind of social mechanics and design features of VR is best suited to deliver a science experience via VR?	Study two
RQ5: how does 3D versus 2D view impact user experience in term of learning and memory in a virtual environment.	Study three

1.4 Research Aims

The research has six aims to achieve, as follows:

Table 1.2 Research aims and how the aim will be addressed.

Research aims	How the aim will be addressed
1. Establish criteria for selecting VR as an appropriate technology for STEM museum exhibits.	Part one of the proposed framework
2. To study the factors that make user experience different across alternative technologies for an interactive exhibit.	Study one
3. To study interactive exhibits in a museum context, with respect to the characteristics of interactive exhibits, visitors' behaviour, and issues around using VR interactive exhibits in STEM museums.	Museum observation study
4. To study social interaction and find a way to support social interaction between visitors when using VR for STEM museums.	Study two
5. To study content design in the virtual environment that supports informal learning for STEM museums.	Study three
6. To create a framework for creating new VR interactive exhibits for STEM museums.	Proposed framework, and proposed framework evaluation.

1.5 Thesis Structure

Chapter 2: Literature review- this chapter presents a review of the literature in this research context. It aims to provide background information related to designing an interactive exhibit for informal learning in museum settings. It starts with defining key terms used in this research. The topics discussed in this chapter include interactive media in the museum context, design process and interactive exhibit design approaches, immersive technology, VR technology, learning and memory.

Chapter 3: Proposed Framework- this chapter provides an overview of the proposed framework and the process of constructing the framework. The detail of each component and the component's elements are described in this chapter.

Chapter 4: Museum Observational study- this chapter discusses the characteristics and issues of using interactives in museums. It summarises results from the museum observational study, including results from general interactive exhibit observation, immersive exhibit observation, and using VR as an exhibit observation. It also highlights the issues associated with using VR in a museum context.

Chapter 5: Alternative Design for an interactive exhibit study (study one)- presents a study which investigates factors that impact user experience when using different technologies. It examines six factors that affect user experience and holding power that indicates the time visitors interact with the exhibit across three technologies: gesture-based interface, tangible based interface, and VR. The results led to suggested factors that should be considered when choosing technology to create an exhibit.

Chapter 6: Social Interaction Design in VR for Museum Study (study two)- presents a study investigating a method to provide social interaction for VR exhibits. It explores factors that influent social activity and communication between visitors who experience a VR exhibit.

Chapter 7: Content design of an exhibit in the virtual environment (study three)- presents a study which explores how 2D view and 3D view perspectives in virtual environments affect users' ability to learn and remember the exhibit's content. This chapter also explores the design content that is suitable for learning from a VR exhibit.

Chapter 8: In the wild study to evaluate the proposed framework (study four)- the study detailed in this chapter validates the proposed framework in the museum setting. Two VR exhibits are adjusted feature match with the suggested components of the proposed framework and deployed in museums. Issues associated with VR exhibit design are identified, and data are gathered from museum visitors to inform the creation of the proposed framework.

Chapter 9: Proposed Framework Evaluation (study five)- this chapter presents a study to evaluate the usefulness of the proposed framework to help designers design a new VR exhibit. It also discusses topics surrounding the design of a VR exhibit.

Chapter 10: Conclusion- this chapter summarises the research. It reflects and discusses finding answers to the research questions. It also discusses the main contributions of the research, limitations, and direction of future research.

The overview of the research methodology shows in Figure 1.1.

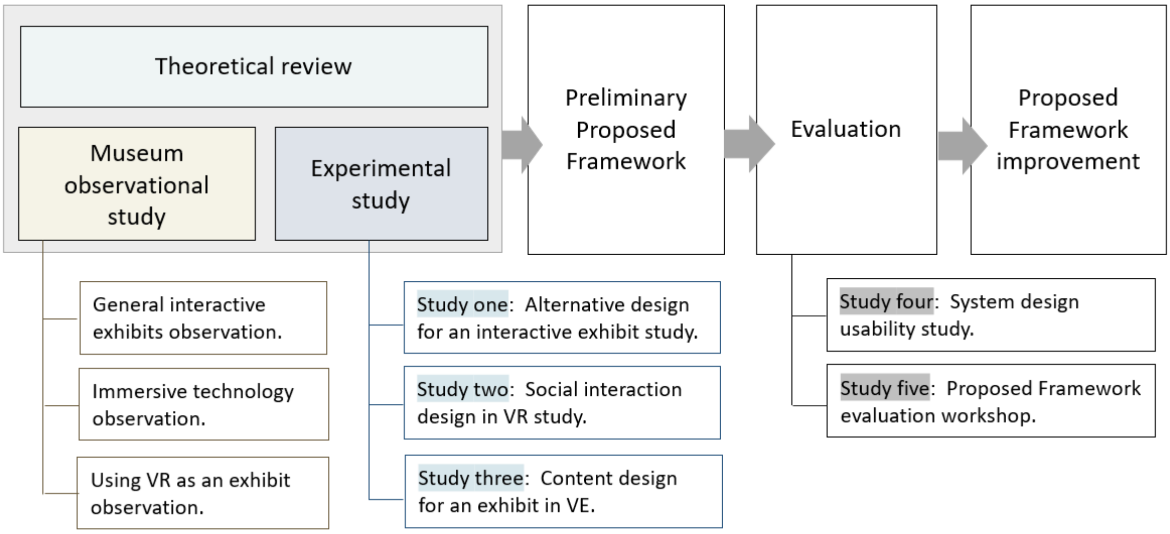

Figure 1.1 The overview of research methodology.

Chapter 2 Literature review

2.1 Introduction

This research focuses on designing a new interactive exhibit by using VR immersive technology. STEM museums are public spaces aiming to deliver STEM knowledge to visitors, so the interactive exhibit should be in the form of media for learning and communicating this knowledge. This literature review will provide background information on the context of designing interactive exhibits for learning in museums. It will cover the characteristics of interactive exhibits, design process, immersive technology, VR technology, learning and memory. These will provide an understanding of the context of this research area.

The chapter begins by defining the meaning of terms used in this research context. Then the characteristics of interactive media in museums will be described (Section 2.3). It will discuss the interactive exhibits in museums, the characteristics of visitors, and the type of interfaces exhibits may accommodate. The next section will explore the design process for a new interactive exhibit (Section 2.4). It discusses the frameworks available to design a new exhibit, how to design an exhibit to engage visitors to play, and what is key to measuring its success.

The next section will discuss immersive and VR technology. Immersive technology (Section 2.5) provides an overview of immersive technology, explains the characteristics of immersive technology, discusses the two key features of immersive technology: immersion and presence, and shows the overview of the immersive system. Section 2.6 will give an overview of the VR technology (the target technology to create a new interactive exhibit) and the VR system's components, including the input, virtual world, interaction, output, and control system.

The last section (2.7) will explore the two key terms, learning and memory. This section will explore the learning theory that can be applied to create educational content and learning experiences through VR exhibits for visitors. It then describes how human memory functions and how new memories are formed. The final topic will explore learning through VR.

2.2 Definitions

2.2.1 Interactive exhibit

The Cambridge Dictionary defines an exhibit “an object that is shown to the public in a museum”. An interactive exhibit is one that allows people (visitors) to interact with it. An interactive exhibit provides something that people can manipulate, like clicking a button or dragging and dropping an object. When people use the exhibit, it responds with feedback, such as showing information on a screen, producing a sound effect, etc. [19] [83]. An interactive exhibit can be referred to by the shortened name, an interactive [4].

The interactive exhibit can be a digital interactive exhibit or an analogue interactive exhibit. Digital interactive exhibits mean using the digital device as a part of the interactive exhibits, while analogue exhibits mean without any digital devices on the interactive exhibits.

2.2.2 New interactive interface

A user interface refers to “the point of contact that enables an interaction between a human being and system” [160]. An interface can be a contact point between a human and a simple artefact like a door. The new interactive interface means a novel way that people can interact with the interactive system.

For this research, a new interactive interface means a new interface for an exhibit. It offers a new way for visitors to interact with the exhibits or a new form of presenting information to visitors. A new interactive interface may include both interaction techniques and interactive elements that people may be unfamiliar with.

2.2.3 Novel technology

The Cambridge Dictionary defines the meaning of a novel as “new and original, not like anything seen before”. According to the Merriam-Webster dictionary, novel means “new and not resembling something formerly known or used.” European Commission [52] used the term novelty based on cutting-edge knowledge, new ideas and concepts. It is not expanding to adjust the existing technology. So, novel technology means a new technology different from existing technology and never used before. Pezzoni et al. [161] show that novel technology can result from combining two existing technological components.

Human-Computer Interaction (HCI) research often uses the term “novel interface” but rarely identifies what it means. Generally, most HCI research that uses this word presents a new interface, a new way that people can interact with systems. For instance, Hashimoto and Kajimoto [82] present a new tactile interface that can offer various types of tactile sensation. Lee et al. [118] present a new interface for an intelligent meeting room which uses hand gestures to interact with the system by selection and pointing. Another word which comes along with novelty is innovation. Summarising the study of Stenberg [206], innovation means doing something different, and innovation can also be defined as a new idea, product, device or novelty. The words novel technology, novel interface, and innovation all refer to a new thing.

2.2.4 Visitors

Visitors mean the museum audience, people who visit the museum. Museum visitors can be visiting the gallery/exhibition inside the museum or visiting online exhibitions. For an example of an online visitor, the Web Lab exhibition at the Science Museum of London allows online participants to interact with the same installation at the museum [73] [41]. Moreover, online visitors can mean people who access online applications that the museum provides for them, such as virtual museums, online collections, etc.

2.3 Interactive media in museum context

2.3.1 Interactive in museum

Museums and science centres are informal learning environments that intend to engage visitors with their exhibits [121]. The components of the museum consist of exhibitions, exhibits, and educational programs. They should inspire visitors to learn more and motivate self-learning [228]. Interactive exhibits in the museum can be characterised as ‘edutainment’, which entertains and educates visitors at the same time. There are typically many interactive exhibits in the same museum, with visitors choosing to play with the interactive exhibits (free-choice learning [55]) and often with limited time to visit the museum, so interactive exhibits in museums need to provide a stimulus to continue in the first ten seconds [90]. The museum environment is designed for individual learners or groups of learners, and the learner will know how to interact with objects in the museum setting [59]. The learning behaviours most commonly observed in museums include cognitive, affective, social, skill and personal [3].

Interactives in museums are developed for an edutainment environment. According to Packer [153], learning in museums is a learning experience for fun, surrounded by a combination of discovery, exploration, mental stimulation, and excitement. Learning for fun has four aspects: a sense of discovery or fascination, appeal to multiple senses, the appearance of effortlessness, and the availability of choice. An interactive exhibit in a museum consists of a short time playing in an interactive style and delivering content that imparts knowledge. Figure 2.1 show an example of an interactive exhibit.

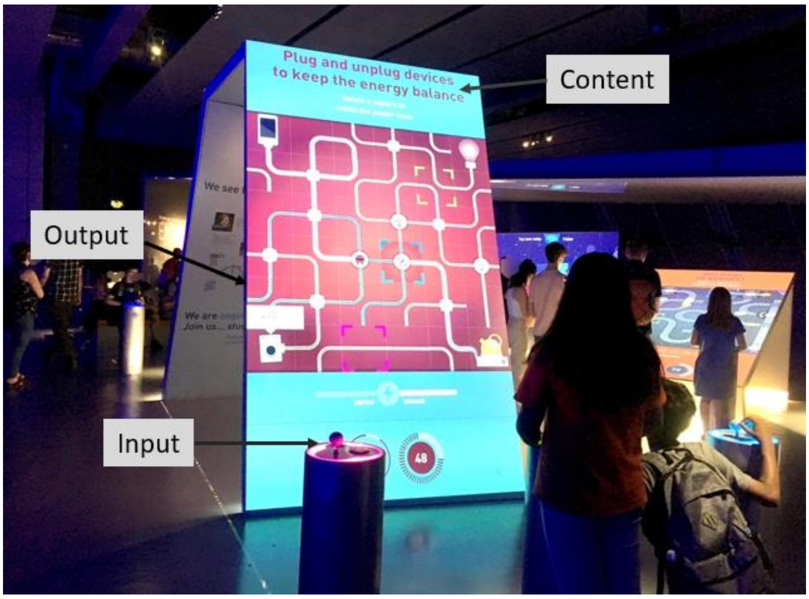

Figure 2.1 An example of an interactive exhibit at Science Museum London. An interactive exhibit composes of input from the system that allows visitors to interact, the output of feedback on the exhibit, the content of the exhibit, and a computer system to control the exhibit behind.

Falk and Dierking [54] suggested three core contexts to consider when designing interactive museum experiences for visitors: personal context, social context and physical context. All three are essential for museums to construct visitors' experience. Each context can be applied to create an interactive experience case by case, and they do not need to be in equal proportion. *The personal context* refers to visitors bringing their own personal background and their interest in visiting the museum and how museums design an experience to support the different backgrounds of visitors. *The social context* refers to social interaction or social activity in that the museum can provide a social experience for visitors. Social interactions play an important role in museum visits. Therefore, the museum should provide social context. Social interaction occurs among family members, groups of students, other visitors, and between visitors and staff. *The physical context* refers to museum building architecture, environment, atmosphere, objects and displays. It focuses on designing exhibitions and exhibits for visitors to experience. To design exhibits, there are two factors to consider. First, how to design exhibits to attract visitors' interest to play an exhibit; this is called the *attracting power* of the exhibit. Second, how to design an exhibit to hold visitors' attention and promote continual interaction is called *holding power* [54]. Figure 2.2 shows the concept of the interactive experience model. The intersection between each core context suggests designs considering both core contexts. The mix between social context and physical context is a design that consider creating a physical museum setting to support social activity, such as creating an exhibit to enable visitors to share social interaction or experiences.

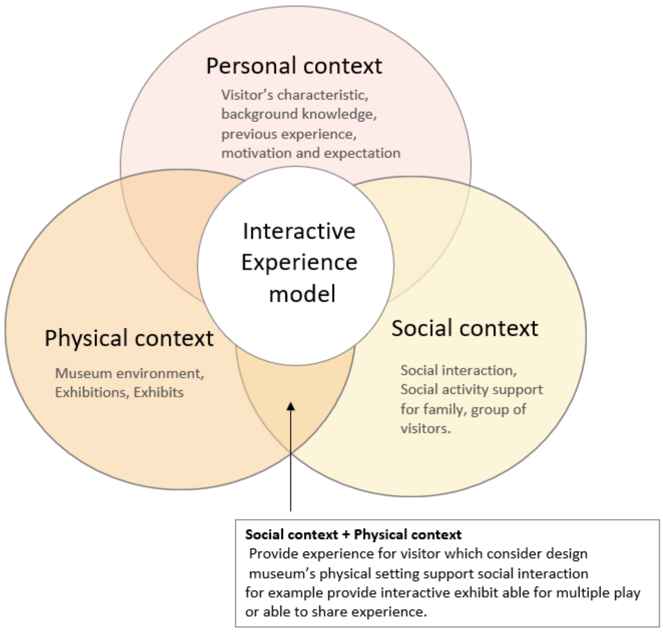

Figure 2.2 The interactive experience model for designing interactive experiences in the museum context was adapted from [54]. The model includes three core contexts: personal context, social context and physical context.

In short, an interactive exhibit in a museum is a display of edutainment media that educates and entertains visitors. It is an interactive for public use. Visitors have a short time to play the exhibit. Designing an interactive exhibit for a museum considers two things, attracting power and holding power. Considering the interactive experience model, an exhibit should support social interaction in which social interaction plays an important role in the museums' experience.

2.3.2 Character of visitors who is user play with interactive

Museums are a place that people visit in their leisure time. They spend their time in museum settings with a relaxed and aesthetically pleasing environment. They desire to enjoy themselves, find something new and interesting, have fun and learn something [57]. Bickersteth [18] mentioned that the Dallas Museum of Art categorizes visitors to their museum into four groups: observers, participants, independents, and enthusiasts. *Observers* are visitors with limited knowledge of the museums' stories and need a guide to visit the museum. *Participants* are visitors who enjoy learning and would like to have a social experience in the museum and galleries. *Independents* are visitors who are confident with their knowledge and would like to visit the gallery alone. *Enthusiasts* are visitors who are active, confident, knowledgeable and feel comfortable visiting the gallery.

Another classification of museum visitors was introduced by Serrell [189]: that visitors are divided into three groups based on the speed of visiting the gallery. There are streakers, strollers and studies. *Streakers* are visitors who walk quickly through the gallery and look around the exhibition finding exhibits that are interesting to play with. *Strollers* are visitors who move more slowly than streakers. They explore the underlying message of the gallery and may learn more in detail at some exhibits. *Studies* are visitors who pay attention to learn everything, read all text and interact with everything.

Falk and Dierking [56] discussed social interaction between visitors during a museum visit as a group, group of family, or group of students on school field trips. Museums are social setting which facilitate social interaction for visitors. Visitors not only interact with other people in the same group, but also interact with other visitors from different groups. One thing that people like to do in a social setting is watching other people. And, according to Falk and Dierking [56], the subsequent outcome of social interaction is enhanced learning. Visitors who come alone are also able to interact with other visitors. Additionally, social interaction also occurs between visitors and museum staff.

2.3.3 Type of interactive interface

Designers in the digital technology era have many choices for designing user experiences. Many technologies are developed which encourage new consideration of interaction design in various ways. Rogers et al. [168] proposed twenty different types of interfaces consisting of command, graphical, multimedia, virtual reality, web, mobile, appliance, voice, pen, touch, gesture, haptic, multimodal, shareable, tangible, augmented reality, wearables, robotic and drones, and brain-computer. Furthermore, another interface is the Natural User Interface which allows users to interact with the system naturally as humans interact with the real world [168]. There are differences in terms of the objective and purpose of using each interface. Developing each interface uses different techniques and technologies. Moreover, there is a limitation to using each interface. Once technologies are introduced to create an interactive system and they have been successfully and widely used in public, researchers and developers can try to combine them to create novel interactive interfaces.

Different types of interactive interfaces have different inherent attributes and characteristics which will deliver experiences to the user differently. The designer should consider when choosing the interface which experience they intend to provide to visitors. Picking a certain type of interface when creating an interactive system should depend upon which interface is suitable for a given task or activity. In other words, which interface is most appropriate, most useful, most efficient, most engaging, most supportive, etc. A designer's selection of interface type will depend on the interplay of several factors, including reliability, social acceptability, privacy, ethical, and location concerns [168].

2.4 Design process and interactive exhibit design approach

2.4.1 Interactive Exhibit Design Process

Interactive exhibits in museums can be developed according to many models. The general process of interactive design involves four necessary activities: 1) discovery of requirements, 2) designing alternatives, 3) prototyping, and 4) evaluating [168]. The process can move forward and backwards between activities. The requirements for designing an interactive exhibit are to deliver specific experience or scientific content to visitors. The designing alternatives step involves exploring ideas that can achieve the goal of the exhibit. When choosing a technology to create an interactive exhibit, there are many techniques and technologies that can deliver the same activity, allowing interaction with the system. The prototyping activity clearly shows the concrete of an idea to communicate the idea, and the user can try it. The prototype can be a low fidelity prototype, such as a simple paper-based storyboard, or a high fidelity prototype, such as a complex piece of software that has almost complete functionality so that the user can get a real sense of what it is like to interact with the final exhibit. Evaluating aims to complement and improve the product. It may evaluate the product during the design process to check the product meet the user requirements, called formative evaluation. Or it may evaluate a finished product to assess its success, called summative evaluation [168].

One method a designer can apply to design and develop a product is *design thinking*. Design thinking is a method for the ideation and development of products [94]. There are five steps; empathize, define, ideate, prototype, and test. Design thinking is a non-linear process, and it can be a parallel task and a repeated process. Another model is called the Double Diamond model [44]. Its process is divided into four stages: discover, define, develop and deliver. The general activity of the process is divergent thinking and convergent thinking. Divergent thinking is generating possible ideas, and convergent thinking is narrowing down diverse ideas by choosing one which best fits the requirements.

Leister et al. [121] proposed a design process for installations starting with 1) concept, 2) design and detailing, 3) production, fabrication, and installation, and 4) post-opening activities. Each main process has three subprocesses: the client's vision, the designer's intention, and the visitor experience. Liu and Idris [127] introduced a framework for interactive exhibition design by combining the theory between service design and gamification. The service design includes pre-visit, during the visit, and post-visit. The framework wants to engage young people in China to visit museums. King et al. [107] proposed an outline of the process used to develop biology exhibits. There are four processes: discover and understand the phenomenon, evaluate with visitors, design and build the document, and maintenance and improvement.

To summarise the design exhibit process mentioned above, the design involves four phases: 1) Establishing requirements is the first phase. The designer needs to understand the requirements. 2) Idea generation: this phase is the process in which the designer generates an idea for a new exhibit. It covers conceptual design development and detailed design development. 3) Production: in this phase, the designer will bring the idea to design a new exhibit to develop the new exhibit. This covers prototype, testing, fabrication, and installation. 4) Post-opening maintenance: this phase happens after installing the exhibit in the gallery, allowing for visitors to experience it. The exhibit needs to undergo maintenance, be evaluated and may have its efficiency improved.

However, there is a lack of research that proposes a framework for designing interactive exhibits using VR technology, specifically, which includes an emphasis on choosing an appropriate technology or interactive interface for given scientific content.

2.4.2 Visitor engagement

The two main concerns for the museum when using interactive exhibits are how to attract them to play with interactive exhibits and how to hold their interest while learning. Bertini et al. [17] suggested that the graphic user interface (GUI) in exhibit design should have five basic goals. First, it should be innovative to attract visitors to play with the system. Second, it should include user guidance and navigation components to help visitors discover the content of the system. Third, it should be intuitive to make the exhibit easy to use. Fourth, it should be non-technical enough not to scare new users of the computer interface and prevent them from using the system. Fifth, fun is one of the goals of the learning experience, and it should be designed with enjoyment in mind.

Lykke and Jantzen [129] suggested ten experience dimensions for evaluating interactive exhibits in museums: 1) involving: refer to how visitors feel and the emotion involved with the exhibit. The exhibits offer visitors to feel entertained, relaxed, immersed or have a positive or negative sentiment. 2) spontaneous: refer to the design to draw the attention of visitors, and the exhibit has a playful design 3) interesting: refer to the exhibit to challenge visitors, such as solving a problem or generating an obstacle. 4) relevant: exhibit relates the previous knowledge of the visitor, and the visitor feels able to use their understanding to experience the exhibit. 5) learning: the exhibit offers self-development to visitors and increases knowledge. 6) unique: refer to the exhibit has uniqueness in design. It cannot be found or experienced anywhere. 7) interactive: the exhibit allows visitors to interact with it. 8) fun: the exhibit offers enjoyment and pleasurable to visitors. 9) close: visitors feel the exhibit communicate with them, the exhibit meets visitor's individual requirements, and address visitor's issues or concern. 10) authentic; the exhibit offers a feeling of existing "for real", trustworthy and reliable.

Beard and Mounir [57] proposed six components that provide motivation or satisfaction for museum visitors: psychological, educational, social, relaxation, physiological and aesthetic. These factors may be summarised as follows. Frist, the psychological component refers to the sense of freedom, enjoyment, involvement, and challenge. Second, education is the intellectual challenge and knowledge gain. Third, social is the rewarding relationships with other people. Fourth, relaxation is the relief from strain and stress. Four, physiological is the fitness, health, weight control, and well-being. Finally, the aesthetic component refers to the response to pleasing design and the beauty of environments.

Fanichel and Schweingruber [59] suggested a useful framework for helping exhibit designers develop an exhibit for learning science in an informal environment. The framework has six strands consisting of sparking interest and excitement, understanding scientific content and knowledge, engaging in scientific reasoning, reflecting on science, using the tools and language of science, and identifying with the scientific enterprise.

Perry [159, pp.25-39] introduced the Selinda model of visitor learning to support holding participants' interest. It suggested six factors for motivating visitors: 1) curiosity: the visitor is surprised and intrigued, 2) confidence: the visitor has a sense of competence, 3) challenge: the visitor perceives that there is something toward work, 4) control: the visitor has a sense of self-determination and control, 5) play: the visitor experiences sensory enjoyment and playfulness and 6) communication: the visitor engages in meaningful social interaction.

Haywood and Cairns [83] argued that collaboration is not an important feature of children's learning experience in an exhibit, and it seems to be unimportant for connecting learning and engagement. However, they suggested co-presence of others is significant and should be considered as a concept when creating an interactive exhibit. Co-presence of others is based on the concepts of 1) *reassurance and feedback*: the presence of other visitors gives the player confidence to play the exhibit. 2) *distractions*: co-presence from others can increase or decrease player engagement 3) *attracting attention*: attracting the attention of other visitors through the player‘s action to interact with the exhibit. For example, clapping hand motivates the player to play and enjoy when other visitors look at the player. But some time makes the player feel embarrassed if they spend a long time doing that. And 4) *communication*: it found that the player desired to talk to other visitors about their experience and found that when the player desired to talk, it motivated them to learn more.

In designing VR, one of the core concern elements suggested by Hillmann [85, pp. 23-27] is engagement, which covers storytelling and gamification. Gamification is a technique used to design and engage learners to learn with academic content [105, pp. 27-30]. Gamification refers to using the video game elements in a non-game context to enhance user experience and engage users [105, pp. 27-30] [45] [127]. Kim et al. [105, pp. 61-87] suggested the integrative gamification framework for learning and education. It includes four elements to consider: story, dynamic, mechanics, and technology. The story is activities or events that provide motivation for players to experience while playing a game. The story can be an important element that makes the game a fun experience. It provides a key process to achieve the goal of an educational program. Dynamic is the abstract concept of a game that encourages learners to learn and offers learner fun through the story. It mentioned 20 kinds of playful design experiences. Mechanics provides the way how players receive feedback and rewards from the game. Technology refers to the technology, software and hardware, used to implement the game.

2.4.3 Key success of exhibit design

Interactive exhibits in a museum are a learning medium that the museum intends to effectively deliver knowledge to visitors. Bitgood [20] proposed criteria to measure the success of designing an exhibit, with two evaluation measures: visitor measure and expert perspective measure. To evaluate the exhibit using visitor measures, three aspects are suggested: 1) *Measure the behaviour of visitors*, which includes: attracting power, the ability for the exhibit to attract visitors to stop and engage with it; holding power, as measured by the time that a visitor plays with the exhibit; social impact, as measured by how much the exhibit provides social interaction among visitors; human factor impact to measure how the exhibit responds to players; and trace or decay measures to find physical evidence of visitor responses to the exhibit. 2) *Knowledge acquisition* assesses what visitors learn from the exhibit. It considers two processes of knowledge acquisition: memory and comprehension. Memory refers to the ability to remember information from the exhibit, and comprehension refers to the ability for a visitor to develop a belief or opinion from the knowledge they get from the exhibit. 3) *Affective measures*: visitors' interest and/or attitudes are affected by experience with the exhibit, this measures a visitor's satisfaction. It includes three components that can be measured: attitude change toward the goal of the exhibit; visitor interest level in the subject of the exhibit content; and user satisfaction, measured by using self-reporting of the experience of the exhibit. There are many aspects to evaluating an exhibit and Bitgood [20] suggested how to choose the appropriate measurement by considering the goal of the exhibit. If the goal of the exhibit focusses on social interaction, the social impact should be considered as a factor in evaluating the exhibit. It also can combine those measurement aspects, depending on the exhibit's goal.

Success in designing an exhibit requires a design plan. The Generic Learning Outcomes (GLOs) is a tool widely used for planning learning outcomes when designing an exhibit [88, 120] [180]. It can be used as a tool to evaluate and improve to provide an opportunity for visitors to learn from an exhibit. The GLOs tool is composed of 5 categories: 1) *Knowledge and understanding*: visitors' increase in knowledge and understanding, such as learning facts or information from the exhibit. 2) *Skill*: visitors increase in a new or existing skill, such as increasing social skills and communication skills. 3) *Attitude and value*: change in visitors 'attitudes or values, such as change in perception, increased motivation, change of opinion or attitude toward other people, in short a positive or negative attitude effect that relates to the experience from the exhibit. 4) *Enjoyment, inspiration, creativity*: evidence to show that visitor enjoyment, inspiration and creativity. 5) *Activity, behaviour, progression*: evidence to show activity, behaviour, and progression of visitor experience with the exhibit (what does the exhibit intend for players to do?).

2.5 Immersive technology

2.5.1 What is immersive technology?

Immersive technology delivers an experience to the user that, by providing artificial sensory information, gives the user a sense of immersion [122]. The immersive experience is a feeling of a human completely being involved in something (media). Immersion can be divided into two aspects. First, cognitive immersion (or mental immersion) involves the psychological processes and phenomena of the media that make the viewer feel mentally involved in the experience or medium, an emotional state of being involved in the experience. Second, sensory immersion (or physical immersion) refers to the efficiency of the medium that can make the audience perceive appropriate real world sensations in the simulation environment [126] [194].

Museums have adopted immersive media to deliver immersive experiences to visitors for a long time. The classic immersive media is a diorama, normally used to display animal habitats or geological information, especially in natural history museums where it is used to demonstrate the natural environment for visitors to have an experience. Immersive media in museums is often mentioned in terms of an installation, such as museums of heritage, art museum displays, installations of ancient artefacts and history of life [218].

Using immersive media focuses on the experience rather than formal learning [21]. Artificial stimuli can be generated to involve human senses – sight, sound, smell, taste, and touch – in many forms, especially visual and audio [31]. The factors that impact the induced immersive experience include realism of the illusion, dimensionality, multi-sensory stimulation, meaningfulness, mental imagery, and lack of interference [21]. Immersive technology includes four parts: the display, content, controllers, and computing centre [122]. Common visual displays for immersive system includes HMDs, desktop VR, CAVE, and smartphones.

However, the development of computing technology allows museums many possible techniques to create immersive exhibits and deliver immersive experiences to visitors. Currently, immersive technology will often refer to technology under the umbrella of extended Reality (XR), which includes virtual reality (VR), augmented reality (AR), and mixed reality (MR) [28]. XR experiences include generation of new forms of reality, augmenting the real world with digital objects, or bringing physical objects into the digital world [208, 231].

2.5.2 Immersion and Presence

The terms presence and immersion are the key when discussing immersive technology. They have various interpretations from the point of view of many researchers. Different researchers categorize forms of presence and immersion in different ways. In summary, presence and immersion can be described as follows:

Presence

Presence normally refers to the state of consciousness, the psychological sense of 'being there' in the simulation environment [198] [98, pp. 47-52]. It can be measured from subjective and objective points of view. *Subjective presence* is measured from the viewer's feedback as a subject who experienced the immersive media. The viewers give their evaluation of their degree of presence. On the other hand, *Objective presence* focuses on observing behavioural phenomena, comparing how individuals behave in a simulation world to how they behave in similar situations in everyday reality [198].

Presence is normally measured subjectively and via various measurement factors. These factors are grounded in theories researchers have proposed to explain what influences the user's sense of 'being there' [16]. For example, the I Group Presence Questionnaire (IPQ) is a 16-item scale that covers four factors: a general sense of presence, spatial presence, involvement, and experienced realism [182]. Schwind [185] showed an overview summary of 15 presence questionnaires with different measurement factors. They also differ in the number of items in the questionnaire. Some measurements are based on subjective, and some measurements are based on behavioural or physiological. Graf and Schwind [75], it was argued that the standard Presence Questionnaire is not consistent in measuring presence. They investigate two standard presence questionnaires, IPQ and SUSa, on the effect of the environment in which the questions have been answered. They found that the result that measurement in VR has different results in the real world.

Immersion:

Immersion normally refers to the capability of the immersive system to deliver the illusion of reality to a human's sense [198]; it is the efficiency of the immersive system that absorbs viewer into it [2] [158]. It can be objectively assessed by considering the property of the immersive system/technology that offers a degree of immersion. The property of the system that offers immersion consist of 1) the system can prevent the viewer from perceiving the physical world (inclusive), 2) the system provides various sensory modalities (extensive), 3) the virtual environment being panoramic rather than a limited field, which surrounds the viewer (surrounding), and 4) the system has the quality of display and resolution of the virtual environment (vivid) [198]. Objective measurement can be carried out using tools such as observing eye tracking to measure the attentional attributes [48] and using Electroencephalography (an EEG test) to measure brain responses to the immersion offered by a system. Objective measurement requires careful interpretation of the results, as studies rarely show and confirm the relationship between the concept being measured and the attribute being measured [2].

As discussed by Sherman and Craig [194, pp. 5-23], immersion can be determined in two ways: mental immersion and physical immersion. Mental immersion has a meaning consistent with a sense of presence, while physical immersion is consistent with a sense of immersion (facilitated by technology) [98] [16] [182] .

A sense of presence is the outcome of immersion: if the system or application has higher immersion, it will provide a user with a sense of presence in the simulation environment [98, 227]. On the other hand, some studies argue that presence and immersion do not directly influence each other via one to one relationship: each facet of creating media is important to create a sense of immersion. Baños [12] discussed that not only immersion but also effective content (content design, the immersive media's story, or narrative) influence the sense of presence. They discussed that emotional environments on non-immersive systems like PC monitors are able to provoke a high sense of presence in the same way as the big screen by using a projector screen 400 x 150 cm. (immersive system). Figure 2.3 illustrates the concept of immersion and presence.

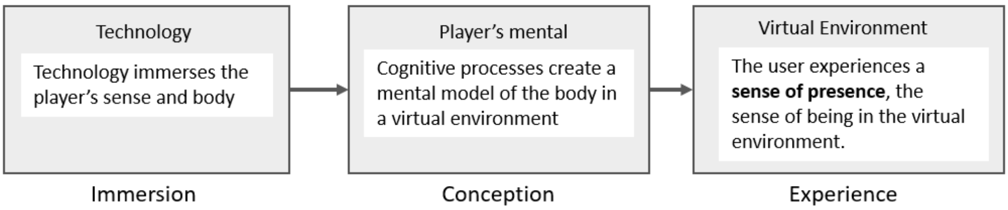

Figure 2.3 The concept of immersion and presence, in which technology immerses players and influences players to believe in being in the place of the virtual environment. Adapted from [93].

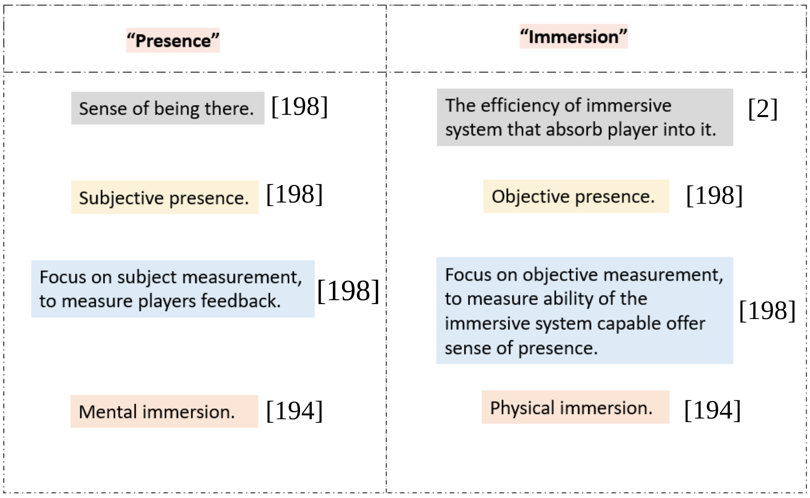

Figure 2.4 Summary of Presence and Immersion concepts.

2.5.3 Immersive technology overview

A literature review of 54 articles on immersive technology by Suh and Prophet [207] proposed a conceptual framework of factors, called the S-O-R framework, related to immersive technology. The framework describes the relationship between immersive system features, user experience using the system, and the result of using immersive technology. The framework consists of three parts: stimulus, organism, and response. *Stimuli* are immersive system features, the input of the immersive system, as described by the framework (see Figure 2.5). *Organism* factors influence users' experience, composed of cognitive reactions, affective reactions, and individual differences. The *response* is the outcome of the immersive technology, which can be positive or negative.

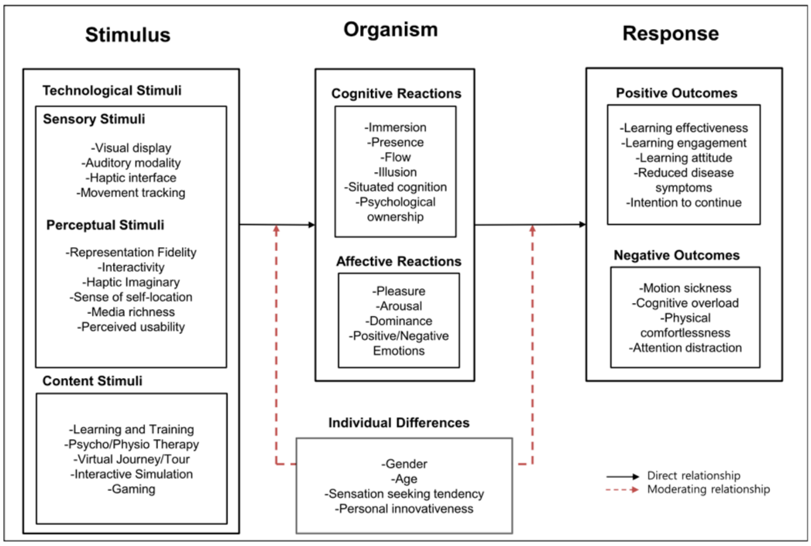

Figure 2.5 The original picture of the S-O-R framework was introduced by Suh and Prophet [207].

2.6 VR technology

2.6.1 What is VR technology

The definition of Virtual Reality, or VR, is not unanimous. Different authors define the meaning of VR differently. However, most describe VR technology as a technology to create and simulate a three dimensional (3D) environments to represent real, imaginary, or artificial environment [133]. The VR technique produces a computer-generated illusion of a place, or reality, and allows players to exist within, and perhaps interact with, an immersive artificial environment [37]. The goal of VR is often to convince users that they are somewhere else [98] [154] [131]. Currently, the majority of studies that mention VR technology focus on computer-generated virtual environments (VE) and VR technology using VR head-mounted displays (HMD VR) [28].

VR experiences can be delivered via desktop computer systems using monitor-displayed VEs, called Desktop-VR. This is done by setting screens around the player with special input devices called Simulator-VR. VR experiences can also be achieved via head-mounted displays (HMDs), where the VE appears inside the headset and players directly see the VE in front of their eyes, called Headset-VR [201]. In addition, Headset-VR provides a fully immersive experience, which allows users to see a virtual world that completely replaces the real world and allows interaction and movement within VE [28].

VR can be classified into immersive VR and non-immersive VR [37] [207], which considers how users see and experience the VE [217]. Immersive VR allows the user to experience being inside the VE, which offers a high sense of presence and immersion, a sense of being there (spatial presence). For example, using head-mounted display VR (HMD VR), the player wears a VR headset, which displays the VE to the user's entire field-of-vision. Meanwhile, for non-immersive VR, the users have experience outside the VE by externally observing the content of the VE through devices which display the content. For example, using a PC and using a mouse and keyboard they interact with the VE on screen, or using a smartphone.

2.6.2 Head-Mounted Display VR

This section will focus on VR HMD, the form of VR used in this research. Figure 2.6 shows the overview of the VR HMD experience. A player is wearing the VR HMD and holding the VR controllers while standing in the physical world (real world). The HMD will display a simulation of the virtual environment, and the virtual environment surrounds the player. The system allows the player to turn their physical head and body to look around the VE. At the same time, the physical body of a player moves the virtual body (VB, also called an avatar) that is used to represent a player in the VE, and which may move according to the player's physical body, head and hands. The VB can move to synchronize with the physical body, facilitated by a system which tracks the position and rotation of the headset and the controllers. The player may be able interact with 3D virtual objects by pressing a button on the controller to provoke an action. The feedback can be visual feedback, which changes the VE, audio feedback, or haptic feedback, as some controllers can generate vibration.

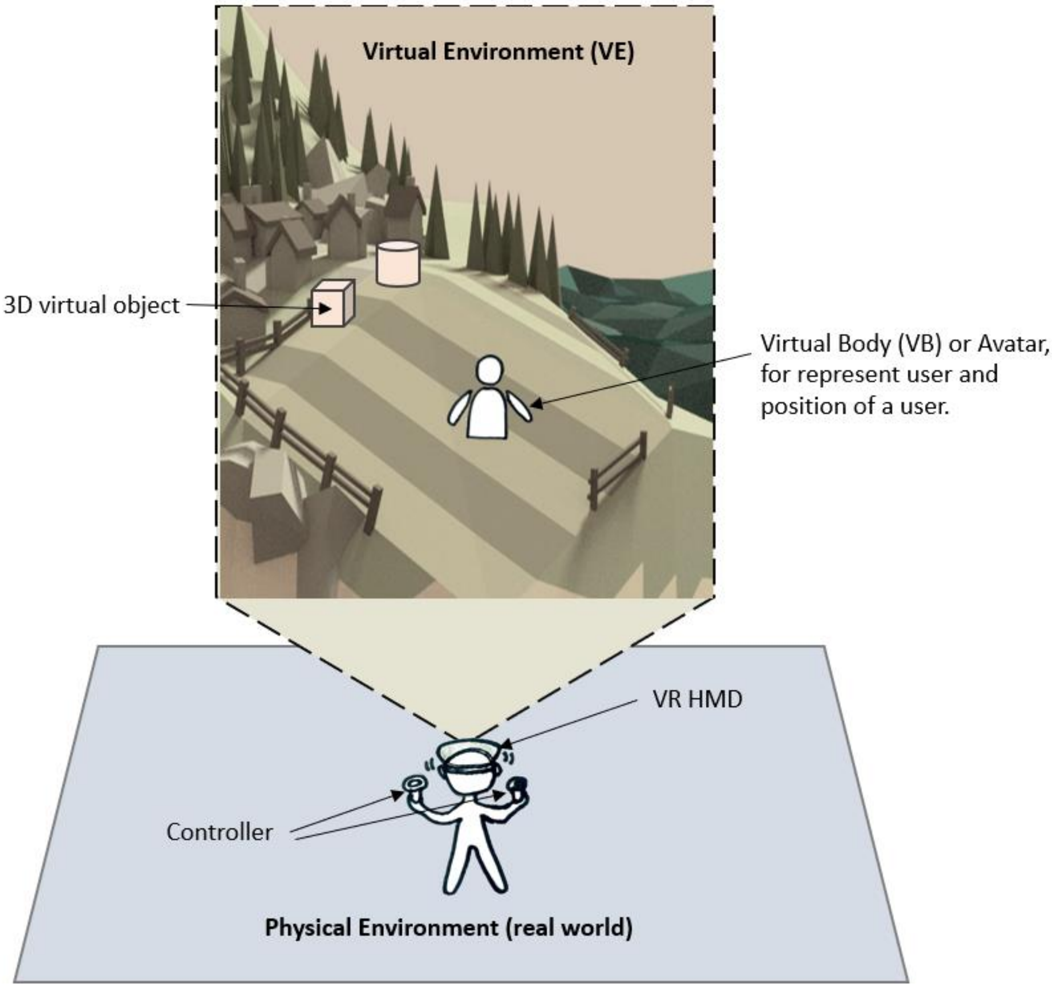

Figure 2.6 VR HMD experience overview.

It can discuss HMD VR systems from summary information in Doerner et al. [47], Spaeth and Khali [204] into five parts: input part, virtual environment, interaction, output device, and control system. The input part includes the headset, the controller, and the tracking system. The virtual environment is the visual simulation displayed for players to experience which can have interactable and static 3D virtual objects. The interaction part describes how players interact with the VE and how they move and navigate within the VE. The output part provides feedback to players, normally visual feedback through the HMD and audio feedback through an embedded speaker on the HMD. The control system manages the input and output of the system. It processes input data to respond to users when they interact with the system. Figure 2.7 details specific parts that will be discussed below.

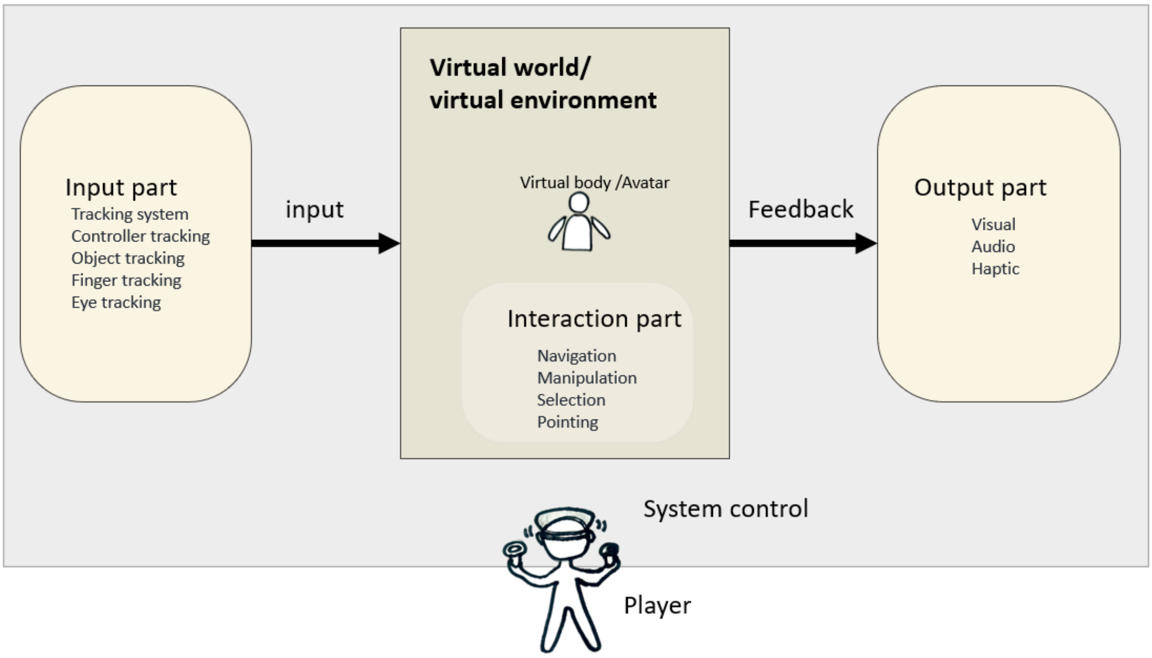

Figure 2.7 The overview components of the VR system. The player wears HMD and uses controllers to interact with objects in the virtual environment (VE). The player can move and navigate themselves in the VE and can manipulate, select, and point to virtual objects. When the player moves, the virtual body (VB) normally will move according to the player's movement. The player receives feedback from the output device in the form of visual, audio, or haptic feedback.

2.6.2.1 Input part

The input part consists of devices that receive data and pass it to the system controller to facilitate the processes. Examples of the input data include the position of the HMD and controller from the tracking system action, or input from the controller made by the user to interact with the environment. The input devices encompass three key important inputs of the VR system: type of HMD, degree of freedom, and the tracking system.

Type of VR HMD

There are many types of VR HMD, and each type has specific features which enable players to interact with VE. The types of VR HMD may be grouped into three categories [204] as follows.

1) *PC-tethered HMDs*: the headset does not have a computer embedded in the headset and requires a PC to run the VR system. It normally uses the PC to connect all devices of the VR system and the tracking system. The source of power also plugs from

outside the headset. Examples of PC-tethered HMDs include the HTC Vive and Oculus Rift.

2) *Mobile VR HMDs*: the headset does not have a computer embedded in the headset but requires a smartphone to run the VR system (for example, Google Cardboard and Samsung Gear VR). The headset is designed to have the smartphone mounted on it and provides built-in short focal distances lenses (2-5 cm) [72] that help viewers perceive the image and improve the VR experience. The phone will use an installed application to display the VR content. The viewer's motion (head movement left, right, up, down, side-to-side) will be tracked by phone.

3) *Untethered HMDs*: this category of headset has a computer embedded within to run the VR system. It has built-in power to run the device, and it also includes a tracking system.

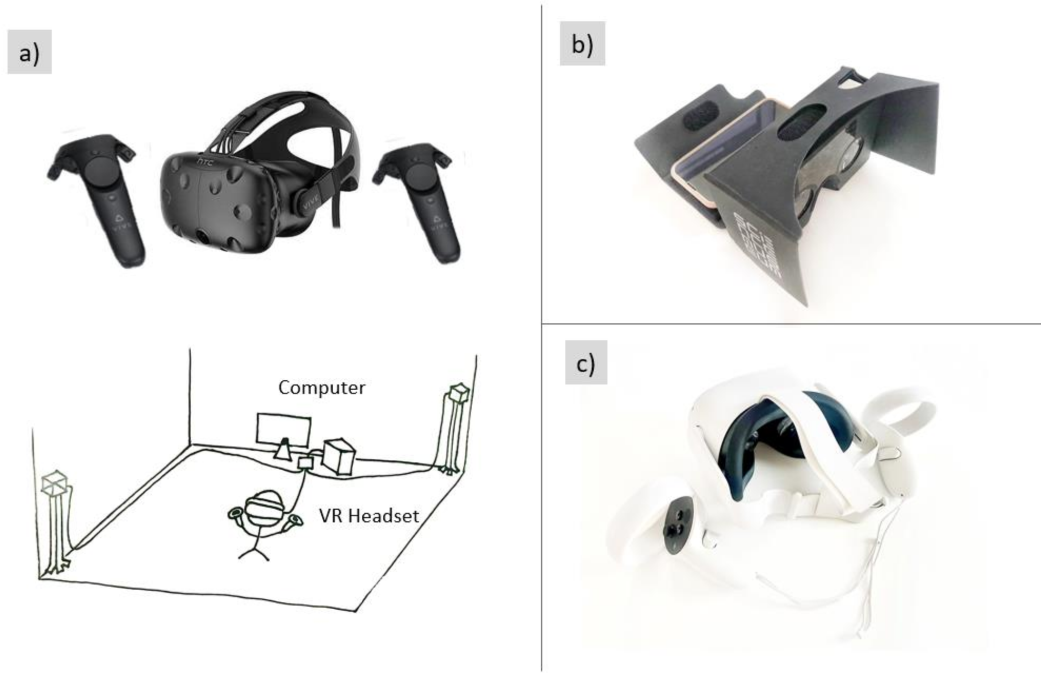

Figure 2.8 The three categories of VR HMD: a) PC-tethered HMDs which the VR headset connect with a PC, b) Mobile VR HMDs, and c) Untethered HMDs.

Degree of freedom (DOF)

Each headset's degree of freedom (DOF) allows players to move inside the VE differently. There are two different DOFs that HMD are able to track, three degrees of freedom (3DOF) or six degrees of freedom (6DOF) [204] [35].

3DOF: the headsets enable tracking of rotational motion and send the input data to the VR system for mapping the movement of the VB in the VE. The three types of rotation that 3DOF can track are: 1) *Rolling*, where the head rotates side to side (i.e., when tilting the head left or right); 2) *Pitching*, where the head rotates along the vertical axis (i.e., when looking up or down); 3) *Yawing*, where head swivels along the horizontal axis (i.e., when looking left or right).

6DOF: the headsets enable tracking of both rotational motion and locomotion position. The data from tracking can then be used by the VR system for mapping the movement and position of the VB in the VE. 6DOF adds to the ability of 3DOF and can track changing the player's position in the physical world. *Elevating* is where the player moves up or down. *Strafing* is where the player moves left or right. *Surging* is where the player moves forward or backwards.

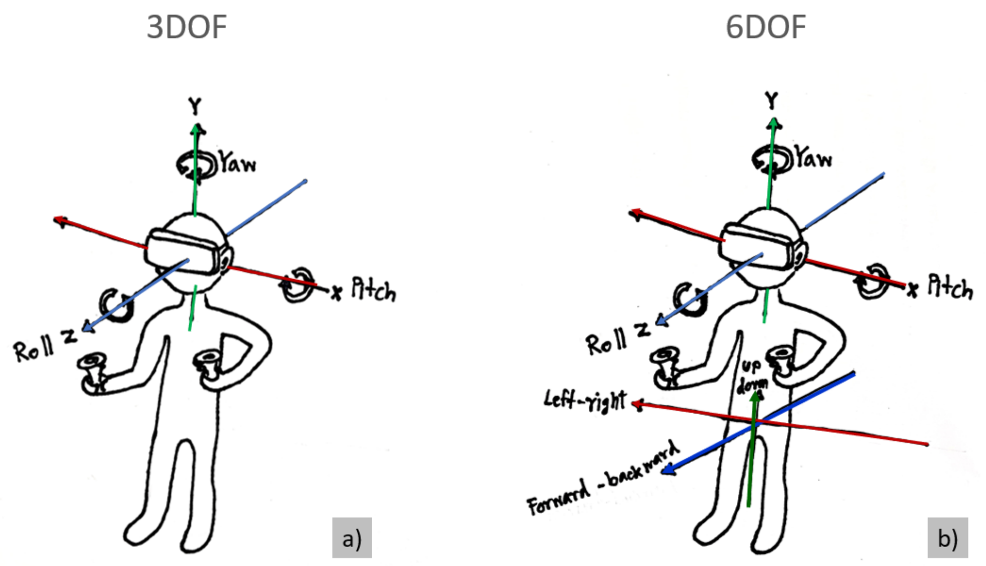

Figure 2.9 The degree of freedom that headset is able to track.

Tracking system

The positional tracking system is used by the VR system to track the position of the player in the physical real world and map the position of the virtual player in the virtual environment. The position is sent continuously to allow for the position in the virtual world to be updated in real time. The tracking system can be implemented in 2 ways: outside-in tracking and inside-out tracking [204].

Outside-in tracking is when the tracking system setup is external to the HMD, such as the tracking system used in the HTC Vive. The Vive tracking system uses Lighthouse base stations to emit infrared light (IR) out through the HMD, VR controller or objects inside the area. The HMD has light sensitive diodes (optical sensors) to detect the light from the base stations [13]. The duration that the sensor receives can be used to calculate the distance between the Lighthouse and the sensor. Each HMD has many sensors attached, which enable the HMD to indicate its location in the VE. The VR controllers also have an optical sensor built into them.

Inside-out tracking is when the positioning tracking system built into the HMD. For example, the tracking system used in the Oculus Quest [84]. The Quest tracking system uses image data from the camera on the HMD to create a three-dimensional map of the room and data from inertial measurement units in the headset and controller to track head and hand movement, with LEDs on controllers which are detected by the headset cameras. The position of the head, hand and environment are updated in real-time and mapping with the movement of the avatar will represent a user in the VE. The system will create a guardian boundary to keep the user safe from colliding with real-world objects inside the area while wearing VR HMD.

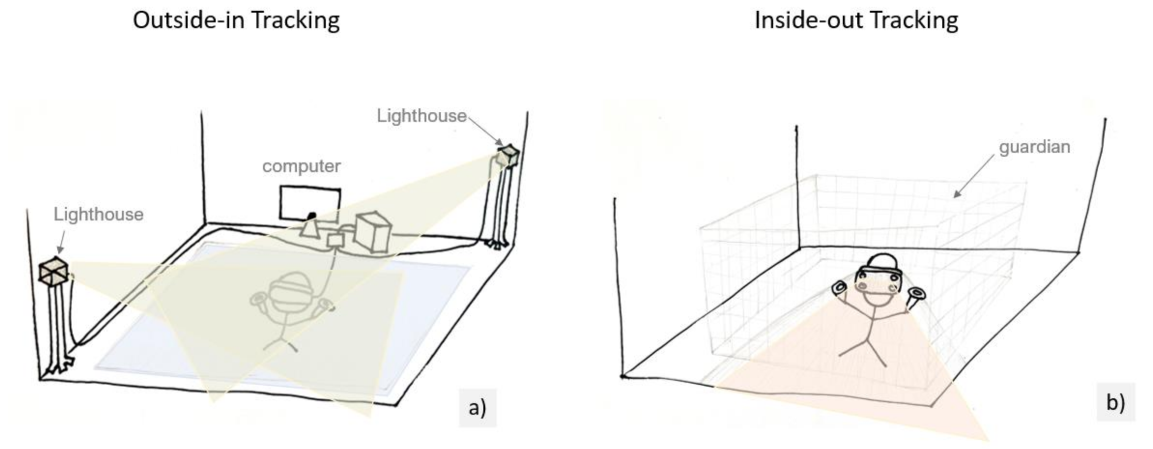

Figure 2.10 Types of tracking systems.

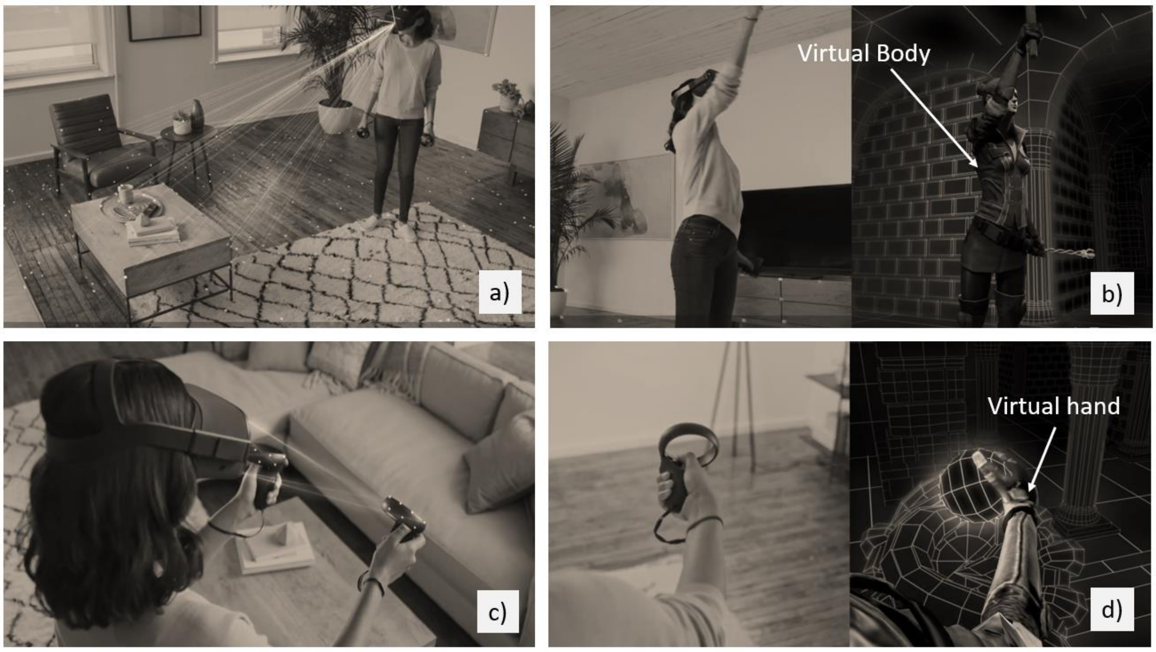

Figure 2.11 Example of the Oculus Quest tracking system [84]. a) the 3D map of the room environment. b) The virtual body (VB) that represents the user in the virtual environment where the head and hands will move according to the player's head and hands in the real world. c) Tracking position of the hand controller, the camera on the headset reads LEDs data from the controller. d) Hand movement in the physical world synchronizes with the virtual hand in the virtual world in real time.

2.6.2.2 Virtual world

The virtual world is the content of VR environments. It is composed of 3D objects which can have dynamic behaviour and may be able to respond to users input in real time [47]. The feature of Terrain (the lay of the land) enables the designer to create a geographic area for the VE, allowing the designer to generate slopes, mountains, rivers, trees, etc. Objects in the scene will be rendered, but the player will only see objects from their current point of view at any given time. The 3D object's behaviour can change according to the state that the developer assigns to the 3D object. The virtual world also has invisible objects to display and the control elements of the virtual environment, for example, sound and light controllers.

2.6.2.3 Interaction

A player can interact with the VE via selection, manipulation and navigation. The player can select and manipulate a virtual object and is able to control their position and direction to explore the VE. This section will discuss the techniques for interaction in VEs.

Navigation that allows players to travel around the VE. There are various techniques used to facilitate locomotion [47]. Locomotion in the VE can be done physically or artificially. Physical locomotion refers to the player physically walking in the real world and mapping their position to move in the VE. Artificial locomotion refers to the player controlling the movement of their avatar to travel around the VE in a different way, such as with an analogue stick. Figure 2.12 summarises the locomotion techniques which allow a player to walk in space. Each technique offers a different experience to the user. For example, a study found using a joystick stimulated motion sickness more than teleporting and walking in place, but all three did not offer a significantly different sense of presence [113].

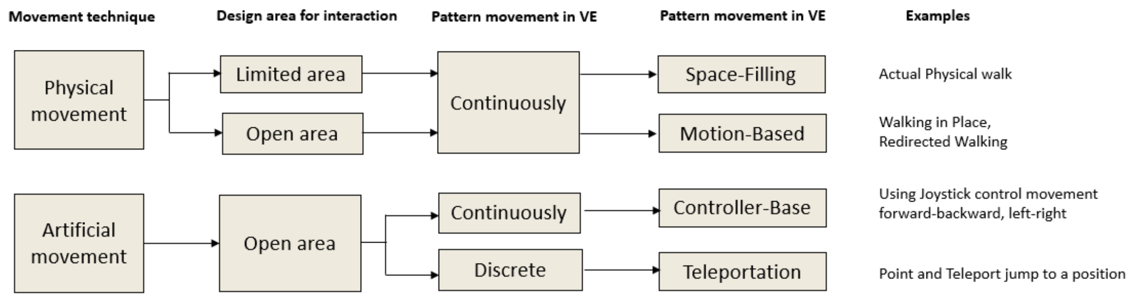

Figure 2.12 Summary of the locomotion technique, adapted from [47].

Manipulation of an object refers to a player interacting with an object for with the purpose of changing its characteristics, such as its position, appearance, shape, or velocity. **Selection** is one crucial interaction for a player to interact with the VE. To select an object, a user normally uses pointing, by aiming a ray-cast at an object. The design of the selection technique can have a significant impact on overall user experience, as poorly designed technique will negatively impact user performance [6]. Virtual object selection can be performed by various selection techniques, Argelaguet and Andujar [6] summarised 32 selection techniques, such as Raycasting, Two-handed pointing, Eye-gazed selection, and Virtual-hand. And they use various selection tools such as using hand avatar, Ray, Cone, Adjustable sphere, and Adjustable cone. Each selection tool has a different shape which is a key issue of accuracy and determines how it is controlled.

VR systems have the capability to offer a collaborative environment. They can allow multiple players to experience the same virtual environment at the same time and allow players to interact with another player and the environment in the same virtual space [194]. The player can perceive another player in the virtual world via a virtual body (VB) or avatar. An avatar is the virtual object that represents the player or physical object in the VE, and the player will embody themself with their avatar [194]. Avatars can enable players to feel co-presence with other players in the VE. VR systems that provides mechanics for players to have social interaction inside the VE are called **Social VR**.

Kolesnichenko et al. [108] studied features of six social VR applications: Rec Room, High Fidelity, AltspaceVR, VRChat, Facebook Spaces, and Anyland. The study interviewed experts and analysed video records from the demonstration experience in each application. The study found that feature design for avatars impacts embodied experience and social interaction in a virtual space. Design avatar depends on each application can make it has more or less aesthetic. However, the performance of displaying the avatar is an issue to concern when designing an avatar's appearance. Social interactions often happen with avatars, for example, handshaking and high fives. However, some social mechanics can happen virtually but do not normally happen in the real world, such as patting the head of other players' avatars or hugging to express appreciation.

2.6.2.4 Output part (feedback)

Visual output and visual feedback

In general, VR HMD offers visual and audio output feedback to the players. The HMD generates images frame-by-frame and changes quickly, allowing humans to perceive the movement of the continuous display image (animation). The refresh rate, or *frame rate*, refers to how often that image is updated per second for display. The frame rate is indicated by frames per second (fps). The framerate impacts how players perceive the smooth motion of 3D objects moving in a scene. Wang et al. [220] found that a higher frame rate provides a better user experience than a lower frame rate, in which a higher framerate of 120 fps is less likely to induce stimulation sickness symptoms than a low frame rate of 60 or 90 fps.

Field of view (FOV) is another factor that affects how players can see the virtual environment. FOV is the angle of view that the user can perceive in VE. It is described by horizontal and vertical angles [25]. Each VR HMD offers a different field of view. Arthur [7] mentioned that FOV affects how players perform a task. A narrow FOV reduces the ability to navigate, reach an object or perceive distances, and makes objects appear nearer than real objects. Lin et al. [125] found that wider horizontal FOV makes players' ability to judge distance more accurate. Lin et al. [124] found that increasing FOV, was more likely to induce simulator sickness.

Audio output and sound feedback

The virtual world is represented with 3D space, and the virtual world also simulates 3D sound. It presents similarly to sound in the real world, whereby sounds surround humans and can come from sources located around the environment. The 3D nature of sound helps humans to understand the environment they live in [193]. In the 3D environment, the listener can discern the direction and distance of where the sound emanated from. This phenomenon is called *localization*. A characteristic of sound that spreads from a specific location is called *spatialization* [193].

To present sound, the design must consider the output channels to which sound information may be presented. Presenting the same sound information to both ears is called monophonic. Alternatively, presenting sound differently for each ear is called stereophonic. The *sound stage* is another characteristic of sound feedback, referring to how sound appears relative to the listener. It can be divided into two characteristics: world reference and head reference. *World reference* is the fixed position of the sound source at one point. *Head reference* is when the position of the source of the sound moves when the player moves their head. For the immersive environment, users tend to prefer world-reference sound to head-reference [193].

Haptic Output device

Haptic output from the system provides the player with a sense of touch. It makes players feel that virtual objects are tangible. Haptic feedback can be delivered by tactile feedback or force feedback [25]. Generally, VR HMD produces visual and audio output for players. Haptic output is an additional output to deliver experience to players which can increase the sense of presence [67]. Currently, VR controllers such as Oculus Quest controllers can generate vibrations that offer vibrotactile sensation to players, vibrating when the player touches a virtual object. Using force feedback devices such as Sense Glove, players can wear a glove that has motors applying force to each finger. It will resist when the player closing finger, simulating a physical object [73]. Kreimeier et al. [109] found that tactile feedback offers presence superior to force feedback.

2.6.2.5 Control system

The control system refers to the computing platform [154]. It controls the processes used to visualize 3D content, handle interaction, and handle input and output data for the VR system. Currently, VR users can access VR experience via web browser (web application), or VR software installed on the device (VR HMD, mobile phone, PC computer). Web-based VR applications (WebVR) allow users to access the experience from a browser. They also provide a platform that enables users to create their own VR experience, for example Firefox Reality [146]. When VR software is installed on the device, the user can access the experience via the locally installed application. It does not require an internet connection if the system does not require access to any online service, unlike WebVR. It be can developed via development software, for example Unity [215] or Unreal Engine [216].

2.7 Learning and memory

2.7.1 Learning theory

Learning is the process of obtaining an understanding of something by participating (e.g. study or experience) in both formal and informal settings [169]. The obtained understanding is knowledge. The way we learn is described by many theories introduced by psychologists.

To develop VR applications, researchers will apply existing learning theories as a guideline to create a learning process, learning outcome, and motivation for players [170] [37]. The use of HMD VR to support Experiential learning (i.e. learning from experience) has been investigated by prior work [62, 112]. VR enables people to manipulate an object by hand and move inside the 3D VE freely. This offers the feeling of an actual experience [112]. Fromm et al. [62] conducted design thinking workshops to show the design elements of VR applications can support a holistic experiential learning process. The Cambridge Dictionary defines experience as the process of gaining knowledge or skill where a human is doing, seeing, or feeling things. Experience is something that happens to humans, and it affects how humans feel, while *learning* is a result of experience. Kolb stated that learning is the process of creating knowledge through the transformation of experience [100].

Kolb proposed the learning cycle model, which has four stages: *concrete experience*, where the learner experiences or notices the experience; *reflective observation*, where the learner interprets and reflects on the experience; *abstract conceptualization*, where the learner generalizes or judges the experience; and *active experimentation,* where learner applies or tests the experience. Experience combines three aspects: (1) an internal or external event of action; which is connected with (2) sensation and perception; and is (3) the result of interpretation [100]. One conceptual framework for designing experiential learning activity called learning combination lock (LCL) is proposed in [14, 226], the concept of LCL based on person interacts with the external environment through the human senses. The conceptual model consists of six factors: 1) The learning environment, *where* the place or the environment of activity occurs. 2) The learning activities, *what* the environment, physical and social setting of learning activities are. 3) The sense *of how* learners receive the learning stimuli. 4) The emotion, how *the heart* responds to the learning stimuli from the external environment. 5) The form of intelligence or skill to be developed. 6) The way of learning, as described by the theories of learning. The external environment: learning place, and learning activity, stimuli a person to learn through the sense by interacting with it. The person perceives and interprets it. And then, the internal environment of each person responds to the stimuli differently based on emotional response, the form of intelligence or skill, and the learning theory best suited for each person. Figure 2.13 illustrates the concept of the learning combination lock.

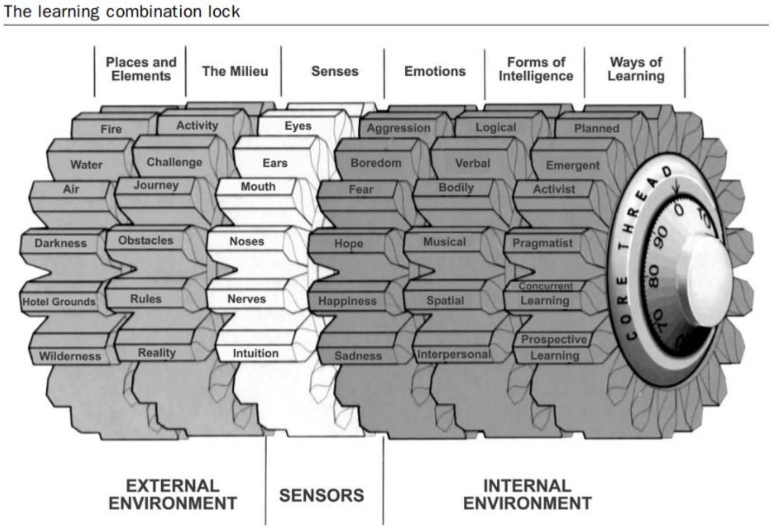

Figure 2.13 The learning combination lock, a conceptual design experiential activities model. Original image from [226].

In the museum environment, a visitor gain knowledge from an individual interacting with the exhibit or acquiring knowledge from interacting with other visitors. So, the theory of constructivism and sociocultural theory are discussed below. They address learning as an individual or learning from interaction with other people. ***Constructivism*** is the theory that focuses on how people develop knowledge when gaining new information and what people do with new information to construct knowledge and understanding. The theory posits that people best learn when the people actively construct their own understanding [169] [100]. However, ***Sociocultural Theory*** instead focuses on the importance of social interaction and cultural aspects of obtaining knowledge [221]. The sociocultural theory regards individual, social and cultural contexts that impact human activities, learning and behaviour. Vygotsky [221] stated that learning is an essential part of a social event and social interaction is key to enhancing learning. The concept of sociocultural theory can be briefly defined by three elements: 1) social interaction plays a significant role in learning, 2) language is an important tool in the learning process, and 3) learning will happen inside the Zone of Proximal Development (Learners learn best when they're at the edge of their ability, so learners need a bit of help/scaffolding to progress.) [106]. It posits that social interaction and language used in conversation with other people are the key processes to learning. Vygotsky stated that when children interact with an object and socially interact with other people, they develop thoughts and express ideas for real things that happen, and transform this into abstract understanding in their mind. Collaborative learning supports the sociocultural theory, which provides the learner with social interaction and supports the learner to interact with other people. It engages learners to solve a problem, complete a task, or explore solutions together. It also enables learners to think and induces talking to share their thinking with other learners [221].

2.7.2 Memory

Memory is the process of taking information from the environment and storing it for the purpose of retrieving it in the future. Memory can be categorised into three types: sensory memory, short-term memory, and long-term memory [8]. Each type of memory has its own function. Sensory memory takes information from the environment and then stores it in the short-term memory. Short-term memory temporarily stores, organises and manipulates information. The information will be stored in short-term memory for a short period, around 10-12 seconds [46]. After that, some information will be encoded and permanently stored in long-term memory. The information that is kept in long-term memory is the information that humans can remember. Long-term memory will keep the information for a lifetime and is retrieved when humans want to use the information. Figure 2.14 summarises the process of acquiring, storing, retaining, and retrieving memory.

Long-term memory has two subcategories: Explicit memory and Implicit memory. Explicit memory is recalled with conscious thought, and it can be divided into episodic memory, which refers to an event or experience, and semantic memory, which refers to facts or general knowledge of the world. Implicit memory is recalled without conscious thought. It is automatic recollection, for example, when performing skills or playing a musical instrument. Implicit memory is also called non-declarative, motor, or procedural memory [46]. Learning retention refers to the ability to store new information in long-term memory that enables learners to retrieve it when they want to use it [15]. If the information is not retained, it means the information remains in short-term memory, does not transfer to long-term memory and then will drop out from short-term memory.

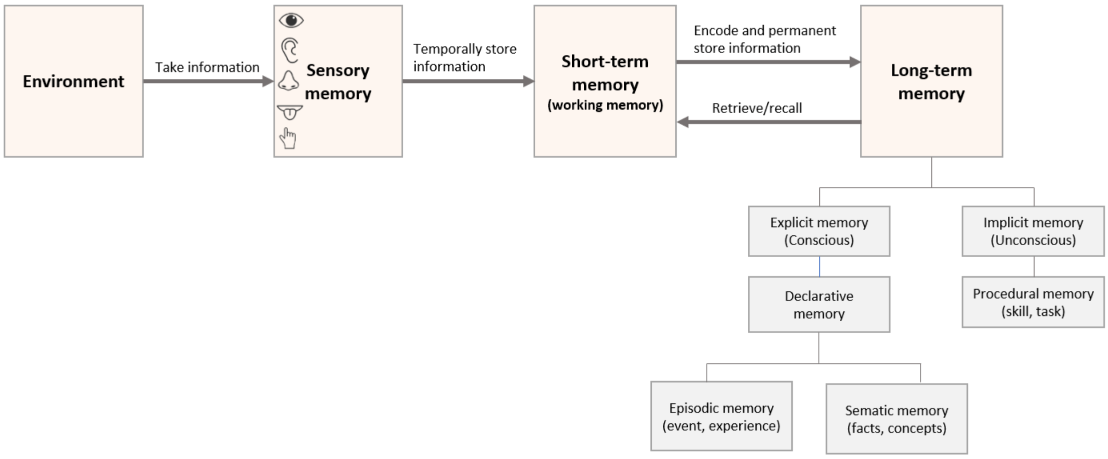

Figure 2.14 Process of human memory and memory type, summary from [174] [8].

2.7.3 VR and Learning

A key feature of immersive VR is the ability to synchronise the player VB in the virtual world with player movement in the physical world, because the capability of VR system can track head and hand gestures in real time. It makes players feel a sense of body ownership or embodiment [184]. Johnson-Glenberg [99] discussed a sense of presence and embodiment as a strong feature of VR that benefits learning. VR embodies the player with their VB in the 3D virtual environment and allows players to *gesture* to interact with the VE. Gesture refers to the forms of movement and interaction used to manipulate virtual objects. And when the player moves and interacts with the VE, this induces sensory motor learning, enhancing memory in which the player can remember the experience more. The belief that learning results from how human physical bodies interact with the environment is described by the concept of experiential learning, or ‘learning by doing’[27]. One positive effect of learning in the 3D environment is that learners obtain knowledge faster and better retain knowledge in their memory. However, the gesture design should correlate well with the learning content. The movement should be designed to be well-matched with the learning content that the learner will learn. For example, in designing a spinning gear system, the speed of rotation in the VE should match the speed at which the learner rotates their hand. If it does not match, the learning concept can be lost.

VR provides a sense of presence for learners, which is the main goal of designing activities for VR learning, supporting constructivism learning theory by allowing learners to construct their knowledge via interaction with the world. The result of an experiment conducted by Johnson-Glenberg [99] found that learners who had performed and manipulated objects in a

VE learned more than participants who engaged in passive learning by only watching the learning content. VR is a useful tool for educators with several key benefits. For example, it makes it possible to display what would otherwise be impossible, reducing danger associated with the actual experience, and reducing the cost associated with travel [9]. However, good content is an essential component of an effective VR learning experience. For example, Johnson-Glenberg [99] proposed the Necessary Nine to be considered when designing gesture interactions in VR, which includes 1) reducing cognitive load by giving one step at a time. 2) guide the learner to do the tasks. 3) give immediate feedback. 4) playtest with end-users often. 5) provide opportunities for the learner to reflex their learning. 6) design activities focus on using hand control, gesture, and body movement for active learning. 7) combine the gesture with the plan for design content to be learned. 8) using gesture for learning are worth the time and reduce simulator sickness. Finally, 9) design gestures as an assessment form so that the learner can demonstrate their understanding.

Social interaction is often mentioned for learning through VR. For instance, in a study of Ioannou and Ioannou [95], students mentioned wanting to have social interaction in VR learning experiences during a visit to virtual heritage site, but the original VR application did not provide them. Okita [151] stated that social interaction is essential in learning. When leaners interact with other people, this will help the leaner to organize their thoughts, and consider their understanding. One can learn by teaching other people or observing other people making their own understanding.

As mentioned, social context plays an important role for museums, as museums are both a public space and a social space [54]. This argues that social activity is fundamental for student learning in the classroom and also in museums, but many VR experiences do not provide social interaction features for learners [95]. Furthermore, designing VR for learning does not emphasise social interaction features because implementing multiuser VR is still expensive [99].

2.8 Conclusion

This chapter has defined key terms used in this research (section 2.2). It discussed various topics that relate to designing a VR exhibit for learning in the museum context. Section 2.3 described the character of interactive exhibits in museums and visitors’ behaviour when playing with the interactive exhibit. Section 2.4 explored the process of how to design an interactive exhibit which engages the visitor to learn and how to measure the effectiveness of an interactive exhibit. Section 2.5 reviewed immersive technology and discussed key two aspects of using immersive technology: presence and immersion. Section 2.6 summarised the VR technology and the key components of a VR system. Section 2.7 discussed learning and memory, exploring learning theories that enable application for learning using VR experiences, as well as explaining how human memory works, and exploring features of VR for learning. The key points of this literature review are listed below:

What are the characteristics of interactive exhibits in STEM museums?

- Interactive exhibits in STEM museums are a learning medium that a museum designs and develops for visitors to experience in the museum environment.
- Interactive museum exhibits entertain visitors while educating visitors by delivering some scientific knowledge.
- The interactive exhibit can be designed with many choices of technology. The various types of interfaces provide a variety of interactive experiences to the visitor.
- New technology is often of interest when designing new exhibits that aim to attract visitors.
- The interactive exhibits in the museum are designed for short time playing, supporting public access and supporting groups of visitors to learn from the exhibit.
- Interactive exhibits are not formal teaching media but informal media for delivering experiences.

What specific requirements do museum visitors have when experiencing an interactive exhibit?

- Visitors have limited time to visit the museum.
- Visitors have free choice to play an interactive exhibit.
- Visitors often come to visit museums in groups of family friends, or students, so the exhibit should provide a feature for visitors to have social interaction between members of these groups.

What is the process of designing an exhibit?

- Designing a new exhibit can apply the process of designing a new product.

- Designing a new exhibit can be summarised into four phases: receiving requirements, idea generation, production, and post-opening maintenance.
- Designing an exhibit for museums should include thinking about how to best engage visitors to play.

What are the key features of VR immersive technology?

- VR is a technology which allows simulation of a virtual environment that makes players believe that they are in another place.
- Immersive technology offers an immersive experience to the player by providing artificial sensory information. It immerses the player such that they feel completely involved in the media.
- By simulating a virtual environment, VR immersive technology offers a sense of presence, where players are immersed in the virtual environment.
- The components of VR comprise five parts: input, the virtual world, interaction, output, and the control system.
- Learning through immersive technology focuses on experience [21].
- VR supports experiential learning, i.e. learning by doing [112] [62].
- Sense of presence and embodiment is the dominant feature of HMD VR that benefits learning. Embodiment, where the player is embodied with a VB, allows the player to move and interact with VE to improve memory [99].
- Using VR has a negative effect on stimuli motion sickness.

Chapter 3 Proposed Framework

3.1 Overview

The main goal of the research is to propose a framework that acts as a guideline to creating a new VR interactive exhibit that supports social interaction. So, this chapter will describe the concepts behind the preliminary proposed framework. The proposed framework has two main parts. The first part provides a factor for checking whether VR technology is appropriate for creating a new interactive exhibit according to the requirements. The second part provides components as a guideline for creating a new VR interactive exhibit. The overview of the preliminary proposed framework is shown in Figure 3.1.

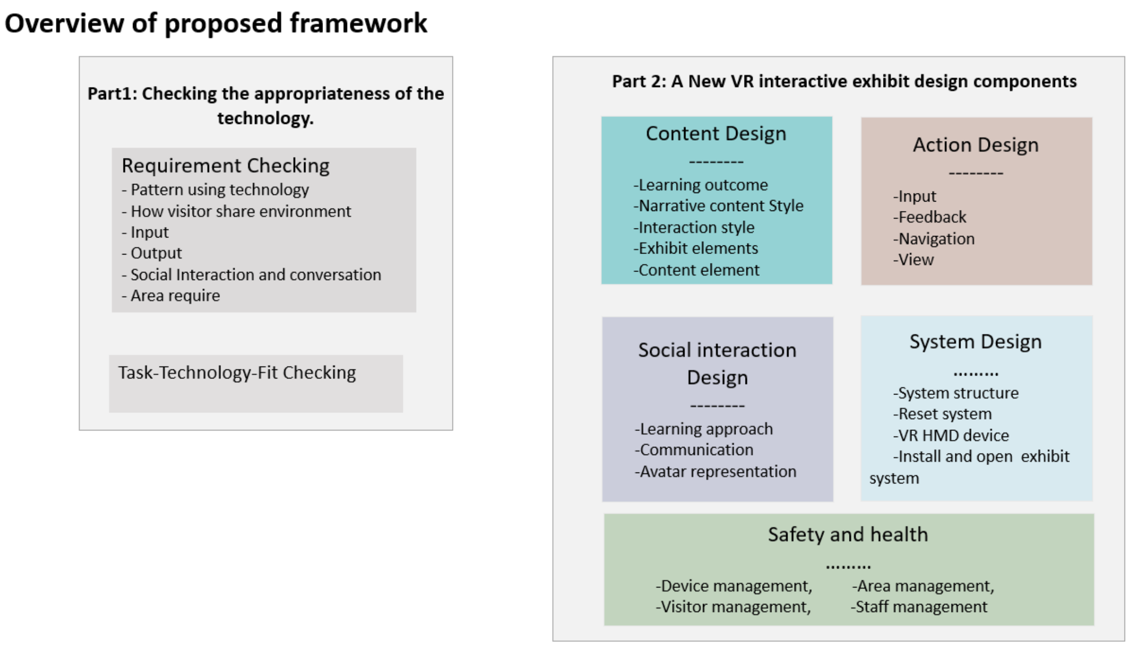

Figure 3.1 Overview of the proposed framework, a guideline to create a new VR interactive exhibit. It is composed of two parts: Alternative immersive technology choice and a new VR interactive exhibit design components.

The framework helps the designer plan a new VR exhibit. The initial aim of the framework includes three things: 1) how to choose technology to create a new interactive exhibit, 2) how to create social interaction for VR immersive exhibit, and 3) how to create scientific content, presentation, and a story narrative that is suitable for VR immersive technology.

3.1.1 The General Steps for Constructing the Proposed Framework.

A framework was constructed in different ways based on the purpose of the framework. For example, a study developed the framework from analysis of the information from a literature review related to the framework's context [207]. Moro et al. [144] constructed a framework divided into 5 phases: phase one reviews the related paper with the framework's focus area to identify the problem; phase two develops the proposal of the framework by reviewing theory, analysing value factor drivers of framework's aim and then elaborating on the preliminary framework to construct and define components of the framework; phase three gathering some feedback with stakeholders to analyse the framework by face to face interview; phase four has an expert evaluate the proposed framework and tests the proposed framework; phase five uses the data from evaluation of the framework to improve it for the final version. Another study, Balilah et al. [11] develops a framework in four steps. First, criteria are generated to evaluate peer-assisted learning programs by using an interview with three questions. This led to finding important factors of the framework. Second, generate the framework template by adapting and analysing the existing model. Third, testing the proposed framework with program leaders by interview (testing the questions in the proposed framework to gather feedback). The last step, finalise the proposed framework and enhance it by comparing the framework with framework develop by another research.

In summary, the general steps to construct a framework are: 1) Understand the context and how theory relates to the aim of the proposed framework area. The information can be derived in many ways, for example, through a literature review or experience with the previous frameworks. 2) Construct and define the components of the framework. In this phase, the initial component will be defined by analysing the gathering of information and theories. After the initial component is constructed, some studies are iterated to confirm the design components by empirical data such as face-to-face interviews with stakeholders [143]. 3) In this step, an evaluation is made after constructing the framework to assess the framework's usefulness and identify area to improve. Evaluation can be done by experts or by testing the framework. 4) The final framework, after collecting results from the evaluation phase, is adjusted to arrive of the final framework.

3.1.2 The Proposed Framework Development

Figure 3.2 shows the steps to develop the proposed framework. The proposed framework was constructed by mixed method, including literature and theoretical reviews, control experiment, museum observational study, and a workshop. It is grouped into four phases: understanding the context and theory, constructing and defining the components, evaluating the proposed framework, and finalising the framework.

Phase 1 is understanding the context of exhibits in museums and applying VR to create an exhibit. This phase starts with step 1, conducting the museum observational study to gather characteristics of interactive exhibits in museums. Step 2 conducted an experimental study of the alternative designs for an interactive exhibit to answer the question of how to choose technology to create a new interactive exhibit. A variety of technologies were introduced to create interactive exhibits in museums. To understand and find evidence to decide how to choose the technology, the study was constructed in step 2. Step 3 gathered information about using immersive technology in STEM museums. It conducted a museum observational study comparing VR immersive technology and other immersive technology focused on social interaction between visitors. Step 4 conducted the museum observational study to gather information on using VR technology in museums. It aims to find issues and patterns of using VR technology. Step 4 also reviewed online media of target and leading STEM museums to find more information that covers onsite and online exhibits (museums media). The end of this phase makes the researcher understand the context of using VR exhibits in STEM museums and the issues they should plan to cover in the framework when designing a VR exhibit.

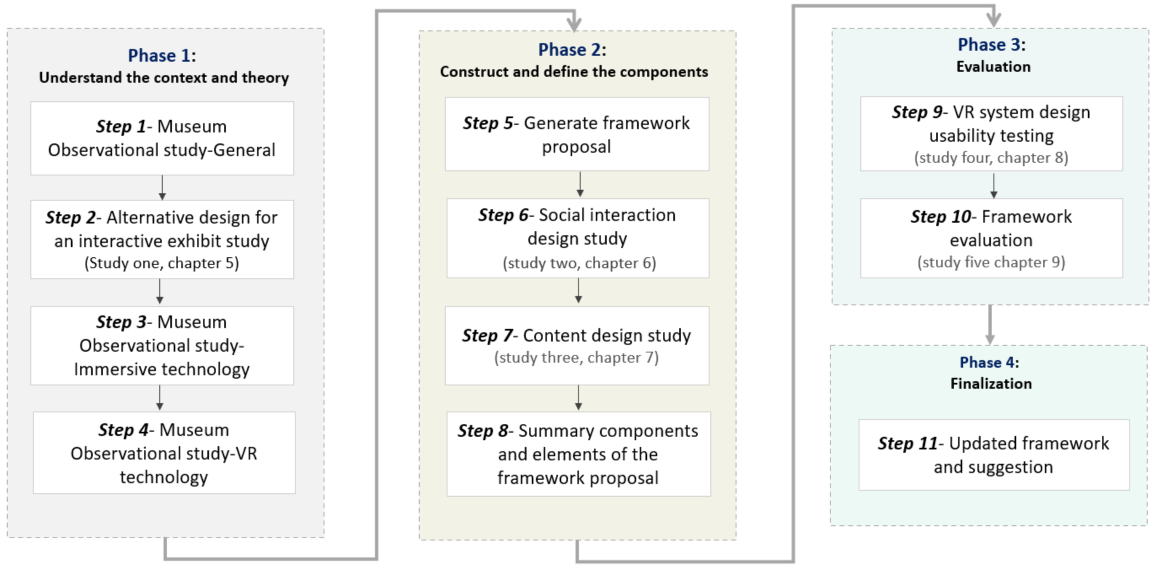

Figure 3.2 The steps of developing the proposed framework.

Phase 2 constructed and defined the components of the framework. In this phase, the components and elements of each component of the framework were created. This phase starts with step 5, generating a framework proposal. Data are analysed from phase 1 and a literature review of learning theory, interaction style, and gamification. All data were analysed to generate core components of the framework. The elements of each component are then roughly defined. The social interaction design study was conducted in step 6 to define the detail of elements of each component and to achieve other aims of the proposed framework on how to create social interaction for VR immersive technology. Step 6 did the experimental study on social interaction, designed to find evidence and support information to define elements of the social interaction design component. The summary data of the experiment and literature review communication theory, social VR and avatar design were used to define and adjust the elements of the social interaction design component. Step 7 did an experimental study on content design to find the answer to the question of how to create scientific content, presentation, and a story narrative that is suitable for use with VR immersive technology. The results of the content design study were used to adjust the elements of the framework components. In step 8, all the information from the previous steps was used to shape the details of the proposed framework. The component and elements of each component of the proposed framework were realigned. This resulted in then, the preliminary proposed framework to be brought evaluated in the next phase.

Phase 3 performs framework evaluation. In this phase, the preliminary proposed framework is evaluated for usefulness and the appropriateness of components and elements for designing a VR exhibit. Step 9 evaluated the usability of the System Design. The VR system design element in the framework adapts from the common element of the general exhibit system. It needs more information to support to design VR exhibit system. Therefore, a usability study was constructed to evaluate the System Design component. The usability study was conducted onsite inside the museum gallery, creating the VR system according to the element of the system design component to allow visitors to play. Feedback was then gathered from visitors after they finished experiencing the VR exhibit. Step 10 ran a workshop with stakeholders who are the target using the proposed framework (including science educators, exhibit designers, technicians, etc.). The aim of the workshop is to test using the preliminary proposed framework. It evaluated the usefulness and appropriateness of the component and elements of the framework by gathering user feedback and analysing how they use the framework.

Phase 4 updates the framework and makes suggestions. This phase will finalise the proposed framework by analysing feedback from the evaluation phase, adjusting the framework and making suggestions for further development.

3.2 Proposed Framework Part 1: Checking The Appropriateness of the Technology.

Developing a new interactive exhibit for a STEM museum will begin with a rough concept of the new exhibit. It will include, as a minimum requirement, the academic topic content, how visitors play the exhibit, what knowledge visitors will take from the exhibit, and where the exhibit is displayed. Therefore, Part 1 of the framework will act as a guide to check whether VR technology suits the development of the new exhibit. The criteria include checking that the desired features of a new exhibit are suitable for using VR technology. For example, if the requirements demand more features than VR can provide, the museum should consider using other technology to develop the exhibit. It is also important to check the task and technology fit (TTF) [205]. It checks that every action required for designing the exhibit can precisely be created by VR. It will ensure that the exhibit will not fail due to insufficient precision of the system when visitors interact with the system. This step should be carried out before proceeding with the detailed design. This is especially true for the interactive exhibits for STEM museums, which often imitate something in nature, such as a scientific phenomenon or animal behaviour, with very specific requirements in terms of action design. Part 1 concerns two components: feature checklist and TTF check.

3.2.1 Requirement Checking

This component provides the initial features of a VR exhibit, as required by the designer's initial aim of a new VR exhibit. The basic features of VR include patterns using technology, sharing experiences in the same environment, social interaction and conversation, area required, input, and output.

3.2.1.1 Pattern Using Technology

The designer should indicate what is the pattern of using VR that the museum aims to create. VR can deliver an experience to visitors in many forms, including online virtual museums, online e-exhibit, continuous onsite experiences, and onsite discrete experiences. These patterns found from the museum observational study in Chapter 4. Online virtual museum refers to the use of VR to create a virtual museum that allows visitors have an online experience to explore each exhibition hall of the museum. Online e-exhibit refers to the use of VR to create an exhibit that allows visitors to access it online. Onsite continuous refer to the use of VR to create an exhibit in a special area, allowing visitors to experience an exhibit continuously from start to end without interruption. Normally, it will set a time for visitors to access it. Onsite discrete refers to a VR exhibit in the museum's gallery that allows visitors to access it freely. However, the experience might be interrupted by other visitors. In chapter 4, section 4.3.3.3, “Results” will discuss this in more detail.

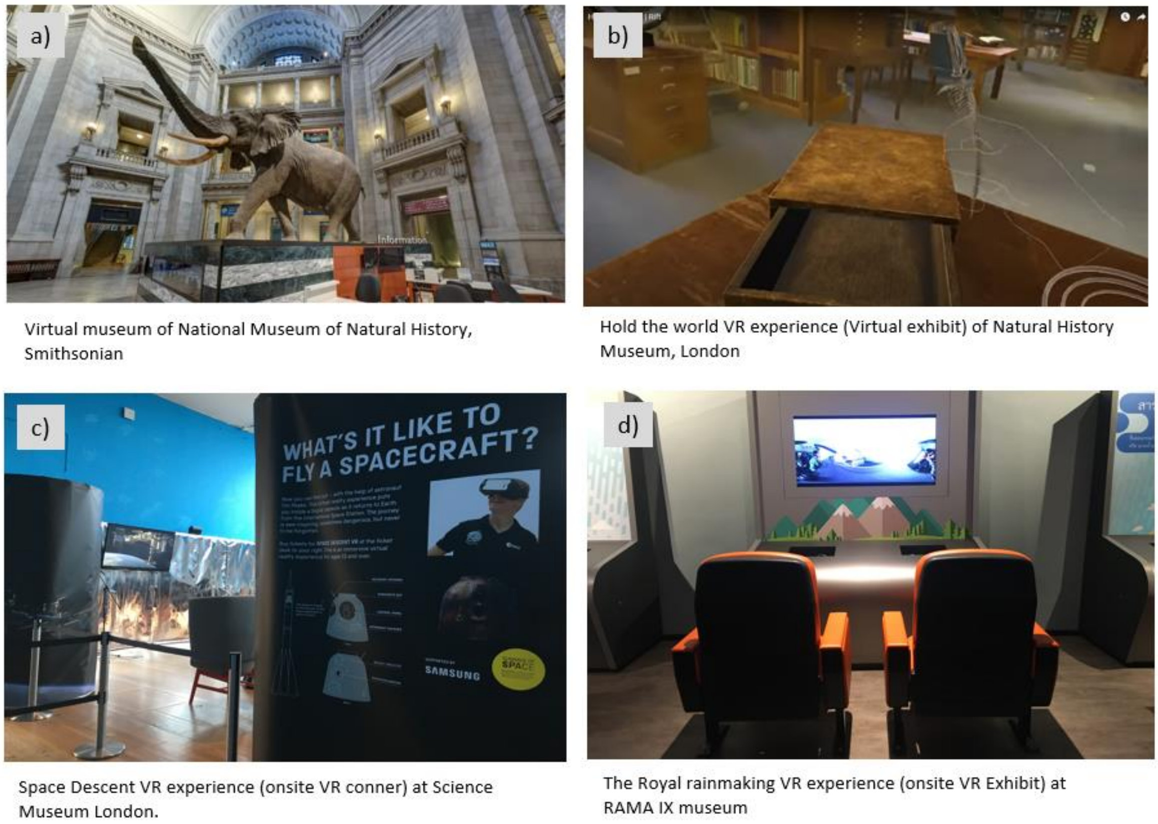

Figure 3.3 Examples of patterns using technology. a) An example of an online virtual museum is the virtual museum of National Museum of Natural History, Smithsonian, US. 2) An example of an online exhibit (virtual exhibit) is the Hold the World VR experience of the Natural History Museum, London. 3) An example of VR onsite continuous (onsite VR corner) is the Space Descent VR experience at Science Museum London. 4) An example of VR onsite discrete (onsite VR exhibit) is the Royal rainmaking VR experience at RAMA IX Museum, Thailand.

3.2.1.2 Share Experience in the Same Environment

The designer should define what kind of experience they want to create for visitors, allowing visitors to share experiences in the virtual environment or play alone. It has two possible options: Asynchronous and Synchronous. Asynchronous refers to the visitors experiencing the exhibit in the same virtual environment, but the visitor is not in the same virtual environment in real time, which means that they cannot share their experience with other visitors. For example, in the Space Descent VR exhibit, each visitor accesses the same VR content but does not experience VR content together. Synchronous refers to visitors experiencing VR in the same virtual environment at the same time. They share experiences and play the VR exhibit together.

3.2.1.3 Social Interaction and Conversation

Social activities are one feature to consider when creating an exhibit. The designer should think of designing a VR exhibit that allows visitors to communicate, discuss, and exchange their knowledge. Some technology does not provide channels for visitors to communicate. Basic VR could design support channels for communication, but some issues were found in the results from the experiment in chapter 6. If the designer focuses on provoking conversation should be considered. The choices include: 1) Watch or listen only, indicating the exhibit did not focus on creating social interaction and aimed for individual learning. 2) Less conversation, where the exhibit allows visitors to have conversations but does not focus on this. 3) Produce conversation between visitors, where the exhibit aims to encourage visitors to have conversations and discussions to share their thoughts.

3.2.1.4 Area Required

VR needs an area to set up safe boundaries for a player during an experience with the exhibit. The needed area depends on the navigation technique and design of the experience. Designers should consider how big a space the museum provides for the setup of a VR exhibit and how the experience designed requires the space. The choices include no area required, small area, and big area.

3.2.1.5 Input

The input of the system needs to be considered together with how the exhibit intends to allow visitors to interact with the exhibit. Sometimes the desired input action is incompatible with VR. The options include passive, referring to the exhibit that intends visitors only to watch and listen to the exhibit story, and interactive referring to the exhibit allowing the visitor to interact with the exhibit. The design should specify what kind of input mechanism is intend for use. Basic VR uses controllers as the input device, and some HMDs are hands free enabling the use of hands to interact with the VR content. This framework only provides for design VR by using controllers to interact with the system. If the designer intends to use another input, this framework does not have information support.

3.2.1.6 Output

Output or feedback of the system is the feedback that the visitors get from their interaction with the exhibit. Visual and audio are the most common output, but current controllers capable of producing vibration, offering haptic feedback to the users. The VR system is able to add additional senses, for example, tactile feedback on an object's texture (touch sense), smell, and temperature (hot, cold). This framework only studies using feedback with visual and audio which is the primary output of the system. If the designer intends to use other senses, this framework does not have information support.

3.2.2 TTF Checking (Task and Technology Compatible)

This component focuses on the technical issue of implementing the interaction that the designer intends to create. Sometimes the interaction is too complicated or task can only be performed poorly. The designer should test whether the intended design interaction is compatible with VR technology or not. Figure 3.4 shows the TTF model which describe the process for TTF check. Frist, define action that designer intent to create. And investigate what are the features of the VR offer to create this action. Second, find a technique to implement this action by using VR. Third, evaluate the performance of the technique. This technique able user perform task precisely.

This component provides the questions the designer must answer include What is the action that you intend visitors to do or how will they interact with the exhibit? How this be implemented, what is the technique that you will use to code the game? Is the technique efficient enough that visitors can interact with the exhibit precisely when using your technique?

This step might require the developer to get involved or include people with the necessary skills to implement the VR application to help test the technique. If the interaction is a general interaction, such as clicking to select an object or dragging and dropping an object, VR can perform the action. If this check reveals the technique cannot be implemented, or the technique cannot be made precise, the designer should consider changing the technique or not using the VR.

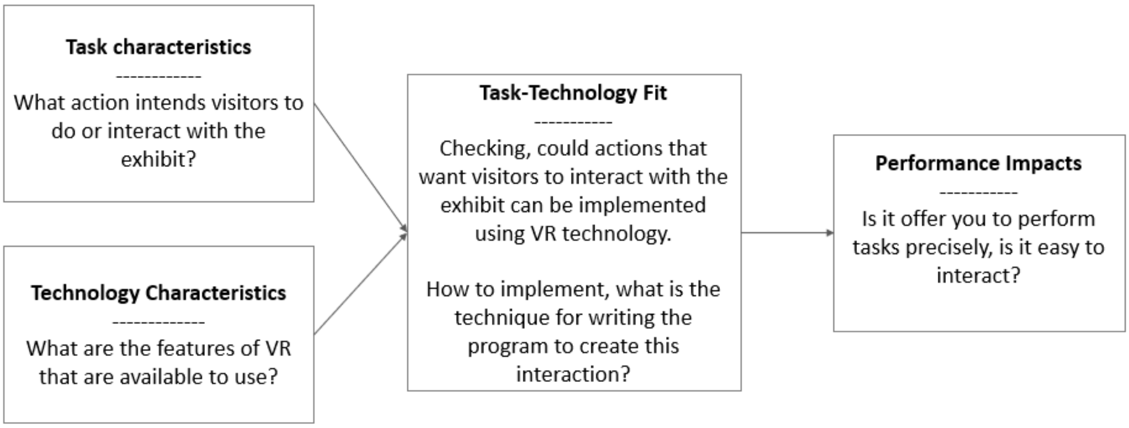

Figure 3.4 Task-Technology Fit model, adapt from [205].

3.3 Proposed Framework Part 2: A new VR Interactive Design Component

The second part of the framework is a guideline to design the conceptual detail of a new VR interactive exhibit that supports social interaction between visitors. It is composed of 5 components, including content design, action design, social interaction design, system design, and safety and health. These components are derived from the analysis of the core components of a general interactive exhibit combined with components of a VR system. The elements of each component are derived from the literature review and empirical data gathered from each of the studies in this research. The element is iterated from many versions after getting new information from the study. Some elements were cut out because they were not studied in this research. Related existing theories have also informed the development of these components. This will be discussed in each component's section.

3.3.1 Content Design

The content design provides a guideline for designing the content of an exhibit. It has four factors to consider including learning outcome, narrative content style, interaction style, and content element (content detail). The content design is the main component of an exhibit. It covers the topic of knowledge that the museums want to deliver to visitors. As suggested in

[21], VR should offer an experience to players, not just give information. A suggestion for designing an experience is storytelling and gamification [85].

3.3.1.1 Learning Outcome

This factor indicates the outcome after a visitor's experience with the exhibit. It has five questions that intend the designer to specify detail. Each question reflects factors in the Generic Learning Outcome framework [88, 120]: doing, feeling, knowledge, skill, and value. It helps the designer think about the outcome of the exhibit for players.

1) What do you intend visitors to do with the exhibit? (Do)
2) What do you intend visitors to feel from the exhibit? (Feel)
3) What knowledge or content do visitors get from the exhibit? (Understand)
4) What skills will visitors develop after the play exhibit? (Skill)
5) What value or attitude will visitors change after the play exhibit? (Value, Attitude)

3.3.1.2 Narrative Content Style

This factor indicates the intention of the designer to create a VR exhibit between Active or Passive interaction design [114, pp. 17-18]. Interactive experience refers to the VR exhibit offers visitors an experienced exhibit by interacting with the exhibit’s content. Passive experience where visitors only read, watch and listen to the story from the exhibit. The designer needs to choose the preferred narrative content style. If the designer intends use Interactive experience, choose one of Interaction Style in Section 3.3.1.3 for create story.

3.3.1.3 Interaction Style

The interaction style provides a guideline for changing content into an experience, and the style of activity creates the player’s experience in the VE. The choice of interaction style was derived from a playful gamification framework [105] and an interaction style found in museum observation (Chapter 4). The interaction style includes exploration, discovery, role play, expression, simulation, create and build, completion, challenge, collaboration, competition, demonstrating a principle, fantasy, sensation, fellowship, relaxation, and sympathy. The meaning of each interaction style is explained in Chapter 4, section 4.3.1.3. Section 6.6.5 discuss more about the characteristic of four interaction styles: quiz, exploration, explanation, and complete a mission, benefit for create social interaction.

3.3.1.4 Content Element

The exhibit element (or exhibit content detail) is a guideline for thinking in detail about content when creating a new VR exhibit. It has five elements to consider: topic content, narrative story, role or rule, time constraints, and reward.

Topic content refers to the topic of STEM knowledge that the designer aims to deliver to visitors.

Narrative stories refer to how to tell the academic content as a story, what will happen in the VE, and what the sequence of the story aims to tell visitors. It relates to the Narrative Content Style (passive or interactive) and Interaction Style. It provides story board for create storyline. The telling story through a science exhibit in a form of science communication, which exhibit telling scientific story to visitors. An approach to construct story for science learning proposed by Engel et al. [51] and ElShafie [50]. The essential elements of story proposed by ElShafie [50] include: 1) Protagonist or the main player, it should be design protagonist balance character between attractive and flaw. Attractive character such as funny, intelligent, resourceful. And empathetic flaw character such as overthinking, fear of attachment, obstinacy. 2) Obstacle, it is a thing to prevents protagonist achieve the objective. The obstacle might from other character, and protagonist's self. 3) Stakes, it makes the protagonist weight to action or make the decision which deal with protagonist must lose. It makes the story more compelling. 4) Inciting incident, it is the catalysed event of the story. It changes protagonist situation that might a new opportunity or threat to the protagonist's objective. 5) Broad theme, the theme of the story is easy for everyone could understand. For example, protagonists are migrating shark and audience learn from follow the shark journey. Engel et al. [51] suggested how to build a science narrative, which includes three types of blocks: Entry Point, Engagement, and Resolution. Entry Point is the blog to hooks learner's attention, examples of thing to stimuli learner attention are compelling objects/assets, problem, puzzling question, choice to choose. Engagement is the blog to engage learner to learn. The examples of engage activities are ask question, explore, investigate, observation. Resolution is the blog of the action of solving a problem. Examples of resolution are introducing the solution, provide the answer, or call learner to take action. It can apply Freytag's pyramid to create structure of the story [177].

Role refers to the mission or rules to play the exhibit. It aims for the designer to specify the activity that players will do in the VE and how to achieve the goal of the exhibit.

Time constraints refer to the time set for the player to do the mission or experience with the exhibit. The designer should decide if they want to set a time for the player to play or allow the player to play exhibit without a time limit. They should also specify how to set a time for the player to experience the exhibit.

Reward refers to the result after the player finishes playing with the exhibit or completing the exhibit's mission. It is a mechanism to encourage the visitor to play.

3.3.2 Action Design

Action design provides a guideline for the design interaction of the system, what input action is, and what feedback is from the system. It refers to how visitors interact with the VR exhibit and what they get from their interaction with the VR exhibit. It has five factors to consider: input, navigation, view, feedback, and controller mapping.

3.3.2.1 Input

This factor indicates what input technique visitors use to interact with the VR exhibit. The input technique that the VR system offer is based on the capacity of VR controllers and HMD. The list of input interaction includes using controller action, body action, and gaze action. The body action and gaze are not covered in this research.

Controller action: design action by using the features of VR controllers. Examples of action are using a laser (raycast) to point and click to select an object, using laser point drag and drop an object, etc.

Body action: design action by using the movement of the body to interact with the system. The VR system has the capacity to track the position of the head (HMD) and the position of the hand (finger, controllers), which enables the player to move the hand or head to interact with the system, see for example [157].

Gaze action: design action by using eye gaze to interact with the system. The headset enables tracking the eye's movement, which offers the designer design interaction by using eye movement, see for example [22] [162].

3.3.2.2 Feedback

This factor refers to feedback that the users receive from the exhibit after they interact with the exhibit. The possible feedback from the VR system includes audio feedback, visual feedback and haptic feedback. The haptic feedback is not covered in this research.

Audio feedback, to specify what kind of sound feedback is provided from the system and when it is provided.

Visual feedback, to specify what kind of visual feedback (texts, images, animation) is displayed in response to user input action, and specify when to give that visual feedback to the user.

Haptic feedback, the new controllers can produce vibration to specify whether or not the system offers haptic feedback to visitors and when. Normally the controller will vibrate when the virtual hands collide with a virtual object [25].

3.3.2.3 Navigation

This factor refers to how players move and navigate in the VE. The players can move around the VE by physical movement (player walking around the exhibit) or artificial movement (using the controller). Section 2.6.2.3 Interaction explains in more detail about navigation. When designing navigation, the space should be considered, particularly the size of the area provided for visitors to move around. The choices of navigation follow.

The physical movement, in which player moves around the exhibit by self-walking in the physical world. The speed of movement is dependent on the speed of the player's walk.

Using controllers for movement, in which the visitor stands at one point and uses the function of the controller to navigate in the VE (artificial movement). The speed of movement is dependent on setting speed in the software. Both controllers can be used to navigate, or the designer can choose one controller, the left or right.

Teleportation is a movement by jumping to a position in VE. A visitor uses a controller in which the visitor stands at one point, points to a position that they want to go to, and then the system will bring, or jump, the player to that position.

3.3.2.4 View

This factor refers to the design view allowing visitors to interact with the exhibit content. Designing view to display content has two options: a 3D view and a 2D view. More detail of view design discusses in Chapter 7.

3D view: design a VR exhibit where players experience the whole virtual environment. The player interacts with virtual 3D objects in the environment surrounding the player.

2D view: design a VR exhibit where players interact with the flat screen inside the virtual environment. It simulates an interactive wall in an exhibition hall in the virtual museum.

3.3.2.5 Controller Mapping

This factor deals with how the designer assigns a function to each button on the controller. It will show the layout of the controller, and the designer needs to think about how the player uses the controller to interact with the content of the VR exhibit. For example, which button is assigned to select an object and which button controls movement. The section 8.5.1.2 discussed more in detail.

3.3.3 Social Interaction Design

Social interaction design provides guidelines to design factors that support players having social interaction in the VE. Having social interaction in VR via interacting with another player via the virtual body (VB), also called an avatar. It is the virtual object that represents the player in the VE. The factors that need to be considered when creating a VR exhibit that supports social interaction include a learning approach, communication, and avatar representation. The detail of social interaction design was studied in Chapter 6.

3.3.3.1 Learning Approach

This factor refers to how the exhibit provides visitors with the opportunity to access the VR exhibit simultaneously. The learning approach strategy intends for visitors to get the experience from the exhibit and includes constructivism and sociocultural learning.

Constructivism: the exhibit is designed for one person to interact with and learn from the exhibit. Its design emphasises that players construct knowledge by themselves by interacting with the exhibit. The VR exhibit is designed for a single player.

Sociocultural: the exhibit design that provides for people to have social interaction during their experience with the VR exhibit. It believes that learning comes from the process of social interaction. Visitors have a discussion and learn from each other. The design of social interaction for the VR exhibit has three patterns: co-presence, co-player, and competition. Co-presence, the VR exhibit allows a player to interact with the exhibit while other people are able to have the experience by observing the player play with the exhibit. Co-player, the VR exhibit allows more than one player to play the exhibit together and help each other achieve the exhibit's goal. Competition, the VR exhibit allows more than one player to interact with the exhibit, and the player competes with other players to achieve the exhibit's goal.

The Section 6.5 discuss more about advantages and disadvantages between single player design and multiplayer design and comparing user experience between using symmetric and asymmetric connection. The section 8.5.1.3 discusses more detail about how to connect player and its benefit according results from deployed the VR exhibits in museum setting.

3.3.3.2 Communication

This factor provides guidelines for designing communication for players to communicate and discuss in the VE. A player can communicate with other players by conversation and use a pointer to indicate the object in the conversation. The section 6.5.4 discusses more about the important of voice and pointer for communication in VE.

Conversation: provide the feature to set up voice for communication in the VE. The behaviour voice in the 3D spatial environment has two options to set up. First, head reference where the sound has the same volume wherever the player is positioned in the VE. The second is a world reference, where the sound volume is according to the distance between the player and the sound source. The designer should specify the distance of sound and minimum volume in case the players are far away from each other.

Pointing object: provide the feature to set up a pointer (raycast) to indicate an object in the VE for communication with other players. The design should define the colour that shows the status of the pointer: normal state and when it hits an interactable object.

3.3.3.3 Avatar Representation

Avatar representation prepares the layout for the design appearance of an avatar. It provides the guideline for each part of an avatar to represent each player in the story, including head, hand, body, and legs. The exhibit may imitate the character of scientific phenomenal such as, animal behaviour. The avatar should be designed with this in mind, and it is possible to design and think about how its movement. Design should also consider where the ray beam is emitted from. Figure 3.5 show examples of the avatar design.

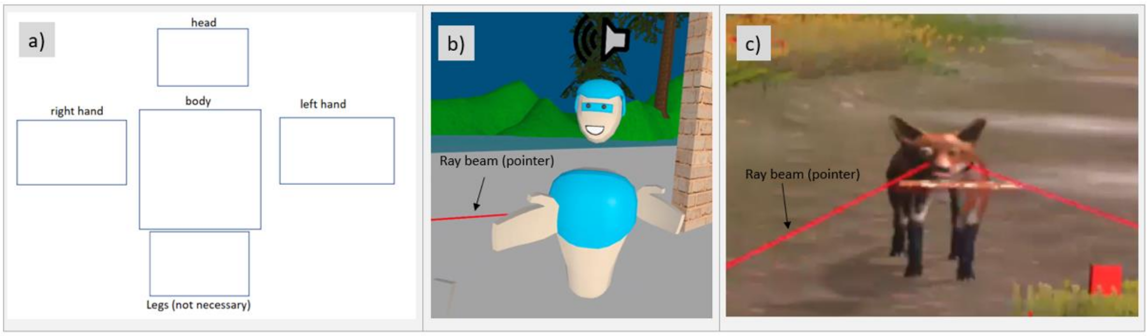

Figure 3.5 Avatar design layout and example of avatar design. a) A is provided layout for the design of avatar appearance. b) An example of avatar design and position of a ray beam (pointer) from study two in chapter 6. c) An example of avatar design and position of a ray beam from study three in chapter 7.

The Section 6.4.4.2 provide more detail about design feature that help to communicate and interact with partner, role of each feature of avatar for social interaction in VE.

3.3.4 System Design

System design refers to the control features of the VR exhibit system that need to be considered when designing an exhibit system. The factors to consider for system design include: system structure, installation and open exhibit system, reset system, and VR HMD device. The Section 8.1.5.4 provide more about concern issues to design VR system.

3.3.4.1 System Structure

This factor prompts the designer to think about the flow of the system. The sequence of experiences that the designer intends for visitors to interact with the exhibit. The flow of the system can be linear or dependent on the condition. The linear system is that visitors experience content of the exhibit step by step. The designer provides a sequence of stories for the visitor to learn without a choice of decision to access the story. Depending on the condition, the player has the choice to select which one they want to play, or the system has a condition to decide what is next for the visitor to experience. The Section 4.3.1.3 discuss more about the common structure of interactive exhibits. The Section 8.4.2.4 provide more about concern issue to design the system structure.

3.3.4.2 Install and Open Exhibit System

This factor provides guidelines for thinking about how to manage the daily opening and closing of the exhibit because the VR exhibit will be open for visitors in the morning and close in the evening every day. The museum staff need to open it and close it, so the design should think about how this is done. Designers make it easy to open and close the system. This factor provides three questions for designers to consider: How to install an exhibit? How to open the exhibit? How to close the exhibit?

3.3.4.3 Reset System

Reset system refers to the system that brings the VR exhibit back to the home page and prompts for the next visitor to play. This feature helps museums manage the exhibit. The reset system is useful in case the previous visitor stops playing the exhibit in the middle of the experience. It will automatically set up the exhibit prompt to play for the next visitor without staff to manage. It has two questions to consider: How to reset the system back to the start/home page? When will the system restart? Section 8.4.2.4 provide a case study to design the reset system for deployed the VR in museum.

3.3.4.4 VR HMD Device

This factor provides the guideline concerning which HMD the designer intends to use and which tracking system for the system to use. The HMD can use a wired connection or be wireless. Each HMD has different features the designer should consider when deciding which one is best suited to deliver the desired experience. Tracking system normally will depend on the HMD that the designer chooses. For example, Oculus Quest has an embedded tracking system while HTC Vive needs an external tracking system. The Section 8.4.2.3 discuss more about concern issue for deployed VR device for public use.

3.3.5 Safety and Health

Safety and Health provides guidelines of factors that designers need to consider safety and health of visitors when using the VR exhibit. The safety and health factors take from the problem found in the museum observational study in Chapter 4. The study found the issue of managing the HMD device, HMD power consumption, and visitor management to access the VR experience in crowded situations. Therefore, this component will highlight the guideline for designing safe and hygienic VR exhibits for visitors to play with. The factor needs to plan for running the VR exhibit in the gallery, including device management, area management, visitor management, and staff management. The Section 8.5.1.5 discuss a case study of Safety and Health provide for visitor when deployed VR exhibit in museums.

3.3.5.1 Device Management

This factor refers to how to manage VR devices in the gallery to prepare for visitors to play. Questions to consider are where to put the VR HMD? It should be in a location that is easy for visitors to see. How to provide the power for VR HMD and controller? The HMD needs power to run, it cannot be used all day without charging. How to design support for charging the HMD and controllers? How to clean the HMD for the next visitor use, a significant concern for personal hygiene, especially during the Covid-19 pandemic. Two options are normally used: using the disposable paper covering mask or using alcohol to clean the HMD.

3.3.5.2 Area Management

This factor lets the designer think about the area provided for visitors to play the VR exhibit. It should be a safe area when the visitor wears the VR headset during play in the exhibit. Design should consider how to make the area safe for players and how big an area is needed to experience the VR exhibit's content. The space provided for visitors to interact with the exhibit links with how to design navigation in the VE, via physical or artificial movement (Chapter 2, section 2.6.2.3 Interaction) [47]. One case study to provide an area for VR players was discussed in Section 8.4.2.3. The play area was created as a line boundary on the floor. VR experience at the Rama 9 Museum and Science Museum London provides a chair for visitors while experiencing the exhibit (Chapter 4 Museum observational study). The two guideline questions are: Where is the area for playing the VR? And How big is it?

3.3.5.3 Visitor Management

This factor of visitor management helps the designer plan to manage visitors to access the VR exhibit in both normal and crowded situations. In crowded situations, the designer should consider if the exhibit uses an exploration style design experience. The time visitors finish playing the exhibit depends on each visitor's interest in learning. In crowded situations, how to manage a chance for each visitor to have an experience with the exhibit should be considered. How to manage the queue? What is the maximum time allowed for a visitor to play the VR exhibit?

3.3.5.4 Staff Management

The Staff management is a factor that helps the designer consider whether the exhibit needs floor staff to manage the VR exhibit. If the VR exhibit needs floor staff to manage, how many and what tasks must they do? If the design of the experience is complicated, or it needs floor staff to help visitors to access the exhibit, this will help the museum plan how to manage the exhibit. There are two questions to consider: Does the exhibit need staff to support visitors to play with the exhibit? What tasks must floor staff perform to support? The Section 8.4.2.5 discuss more about role of staff for VR exhibit.

3.4 Conclusion

The proposed framework aims to provide the designer as a guideline to design a new VR interactive exhibit. It includes factors intended to prompt consideration in planning the new exhibit. The proposed framework is composed of two parts: Part I, Checking the appropriateness of the technology and Part II, A new VR interactive exhibit design components. Part I has two components to consider before choosing VR technology to create a new interactive exhibit. The two components are requirement checking and task technology fit checking. The first determines if VR technology is able to create a new exhibit based on the requirements. The second provides plan to design the new VR exhibit, which includes content design, action design, social interaction design, system design, and safety and health.

The proposed framework was constructed from analysed data from various sources, including a literature review of theory and case study, museum observational study, experimental study, in-the-wild study, and a workshop. Development of this proposed framework is divided into four phases: phase 1 gathering the information and data to understand the feature of the interactive exhibit in a museum setting and VR technology applied in a museum context; phase 2 constructs and defines the components, generates the components and elements of each component by analysing the information gathered from phase 1, and conducts studies to find evidence for designing social interaction and content of VR exhibit, Next the detail of framework proposal is defined; phase 3 evaluation, evaluates the framework proposal in phase 2 for usability to measure helpfulness and appropriateness of the framework’s component. By gathering user feedback, phase 4 finalises the proposed framework and enhances it based on feedback from the user and provides suggestions for further development of the framework.

Chapter 4 Museum Observational Study

4.1 Introduction

Understanding the current situation in the field of research is essential. This research adopt design thinking process that start with conduct the observational study to enable a deeper understanding of the exhibits' characteristics and visitors' behaviour. The main focus is to find issues or areas for improvement. This study applied the IDEO design thinking method [92] to understand the context of using interactives in STEM museums, which led to finding a solution for designing VR exhibits. The IDEO card is a tool that suggests methods to apply in the design process, which emphasizes considering people who use the product. Two methods, shadowing and try it yourself, were applied in this study. The details will be described in section 4.3.1.2.

VR is one of the technologies that can deliver an immersive experience to users. Many museums tend to adopt VR use in their gallery [38]. While VR was introduced many years ago, it is still not widely used in the public space for reasons such as simulation sickness, cost of the device, and hygiene issues [38, 229]. Even though VR technology has the potential to simulate everything in a virtual environment, and produce simulated objects quite similar to those in the real physical world, the VR exhibit cannot replace the value of the real object. Visitors come to visit the museum because they want to see the actual object, and VR is just a tool to supplement the real object [38].

Museums use more than VR HMD to deliver an immersive experience to visitors. There are many kinds of techniques to create an immersion sensation for visitors that museums currently use. However, each technology has advantages, disadvantages and limitations, which the designer must carefully consider when creating an interactive exhibit [5]. Sometimes the technology that the interactive designer intends to use does not go well with the concept of the exhibit [137]. The use of a VR headset designed for individual use but used in a public space with many people may cause some problems, especially in the museum setting with its specific characteristics. While good in theory, the use of VR in a space crowded with visitors may face issues when implemented in a real environment. Best practices from the museum setting should inform interactive design concerns when using VR for the exhibit design.

Museums are public spaces that people desire to visit in their leisure time. Normally, people visit the museum together with friends or their family [54, 64]. The museums are a social space where people share time and space together, having social interaction in a surrounding with scientific content, knowledge and experience. Exhibits are media that museums provide for visitors to play and experience. Each interactive exhibit's characteristics might impact visitors' experience. A better understanding of interactive exhibits in the museum's context will help to design a better VR exhibit.

This chapter will summarise the data from the museum observation and will discuss issues that surround using VR technology as an exhibit. These issues affect visitors' experience based on the evidence found in the observation. Suggestions will be offered on how to create a VR exhibit supporting social interaction, while attracting visitors' attention and encouraging them to play with the exhibit. The challenge designing a good VR experience which found practical constraints in the case study is also discussed in this chapter.

4.2 Study Goals

The observational study had three goals that focused on different purposes:

1) *General interactive exhibit observation*: aim to understanding the characteristics of interactive exhibits, the interface introduced in the STEM museums and the problems in using the interface (technology).

2) *Immersive technology observation*: aims to deeply understand the immersive technology that museums currently use as exhibits and compare advantages and disadvantages with the VR-HMD.

3) *Using VR as an exhibit observation*: aim to investigating how museums use VR, visitors' behaviour, social interaction between visitors, and how museums manage the VR exhibit.

In observation activity, the role that the observer can play, mentioned by Baker [10], includes Non-participation, Complete Observer, Observer as Participant, Moderate or Peripheral Membership, Complete Participation, and Complete Membership. The researcher can choose a role which depends on the desired relationship between the researcher and the people being studied. In a closer relationship, the researcher can get more in-depth data and insight into people. However, relationships between the researcher and the target group affect on data; if the researcher observes from outside the group, the researcher may have misinterpretation cause of unable to know the insight of issue from the group, and the researcher interprets data through the lenses of their own history, experience, expertise, and bias. If the researcher does not part a target group member, it may get fake data from people because of untrust [117]. The length of time to collect data in the field depends on each research question the researcher wants to answer and the role that the researcher selected [10].

The process to conduct the observation started by choosing fifteen museums in the UK and Thailand. The chosen museum, which considers the museum main deliver scientific content, should cover the museum's wide area in the UK. Contacting each museum to explain the details of the study and observing exhibits in the museum. The data was collected by note-taking and photographs without close contact and interrupting visitors [10, 89]. Table 4.1 shows the summary of the observational study.

Table 4.1 The summary of the observational study.

Observation	General interactive exhibit	Immersive technology	Using VR as an exhibit
Aim	Understand the current situation, characteristics, problems, trends of technology, and interface introduced in the STEM museum.	Exploring immersive technology that museums currently use as an exhibit.	Investigating how museums use VR and the issues involved. Focus on social interaction behaviour between people.
Where	Glasgow Science Centre, Science Museum London, NSM Thailand.	Science Museum London, Royal Airforce Museum, NSM Thailand.	Rama IX Museum, IT Museum, Science Museum London.
Method	IDEO cards method: learn, look, ask, and try.	Participant Observation.	Focused Observation on particular installations.
Result	Common characteristics of interactive exhibits.	Various immersive technologies used in exhibits, with associated advantages and disadvantages.	The main issue of using VR as an exhibit in STEM museums is the lack of supporting social interaction between visitors.

4.3 The Case Studies

The detail of the three case observation studies will be separated and discussed by case study.

4.3.1 General Interactive Exhibit Observation

Museum ethnographic studies can help in understanding the characteristics of an interactive exhibit in the museum context [116]. It is important at the beginning of the design process to know the current situation of the research area. The observational study will help the researcher understand the visitors' behaviour who are users of the interactive exhibits and its issues.

4.3.1.1 Study Aims

The study aims to understand the context of interactive exhibits in STEM museums especially focusing on finding common characteristics of interactives in a museum context and visitors' behaviour using interactive exhibits.

4.3.1.2 Study Design

The study uses ethnographic research by applying the shadowing technique from the IDEO design thinking method [92, 130] to observe visitors during play with interactive exhibits in the museum and use the Try it yourself technique deeper understand how each interactive exhibit works. The activities suggested in the IDEO card method include *Learn*: analyse the collected information to classify patterns and deep understanding, *Look*: observing visitors to explore what they do, *Ask*: engage visitors to participate in the research process to gather the information that relates to the research project, *Try*: create a simulation of product and share with people to evaluate the design. Figure 4.1 shows the example of the IDEO card method. The activities of this study include (1) taking photos of interactive exhibits inside the museums, (2) observing how visitors play with interactive exhibits by watching without interruption and (3) taking note of things that happen during the observation. All data (photos and notes) will be analysed and classified. The coding scheme consists of a character, technology, interface design, problems with using the technology, how visitors interact with the system, social interaction and conversation.

The initial study selected 15 museums around the UK and Thailand, but only five museums were observed: Glasgow Science Centre, Science Museum London, NSM Science Museum, Information Technology Museum, Natural History Museum, and Rama IX Museum. This was because data collection was interrupted in this step due to the Covid-19 pandemic. The collected data is enough for evaluation, and the study was narrowed down to focused on VR immersive exhibits to understand how museums use VR and its issues. In which VR is the target of technology for this research.

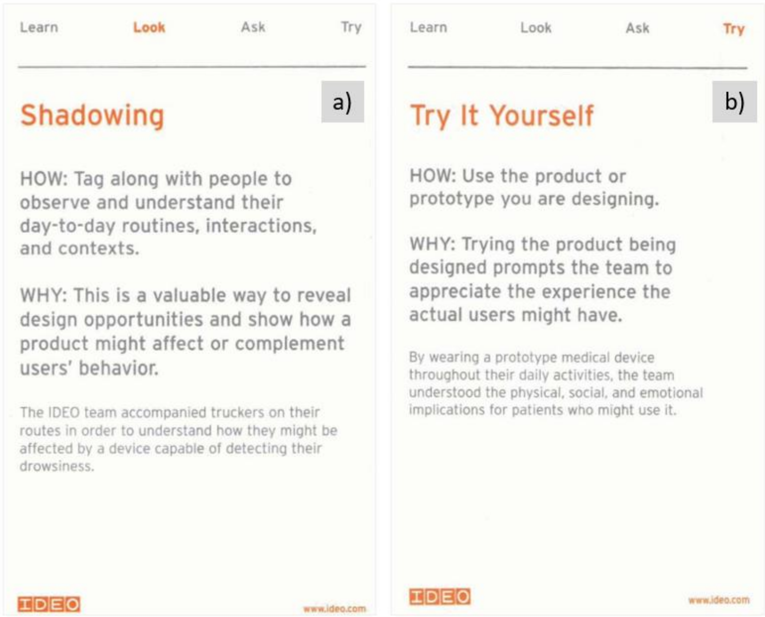

Figure 4.1 Example of IDEO card method, a) Shadowing method, and b) Try It Yourself method.

4.3.1.3 Results

The data from the observation found common interactive system introduce in museums, form of social interaction, and common structure of interactive exhibit in the STEM museums.

The interactive systems often found in museums and figure 4.2 shows the example of the interactive system.

1) Analog system: the interactive exhibit, such as a puzzle game, uses real material to demonstrate science phenomena often found in the form of an analogue format for example, an exhibit covey message of a magnetic force.

2) Physical mechanics: the interactive exhibit uses a mechanical based to create the exhibit, and the system's movement is built by applying a mechanical system or adding an electronic system to make changes or create movement on the exhibit. For example, the wind turbine exhibit uses mechanics to build a turbine where visitors can adjust the blade pitch by controlling a joystick to capture wind energy. And wind also uses mechanics to generate.

3) Touch screen system: the touch screen is quite commonly used in museums. It can be the input device and visual output device of the interactive system. The touch screen can be a single touch or multiple-touch screen system that allows more than one player to interact with the system at the same time.

4) Gesture system: the gesture system allows players to use their bodies to interact with the system, especially using their hands. Often, the system allows visitors to use their whole-body movement to interact with the system.

5) Tangible system: the tangible system allows players to touch the physical object, which is an input of the system to control the digital content [96]. Sometimes the tangible interactive system is called hands-on [171]. The simplest tangible system is an interactive one that engages visitors to push a button to activate a display of the content. Another tangible system is one that changes input devices from a mouse and keyboard to another device to control the computer system, for example, using a joystick or an object from daily life with an attached NFC tag. The tangible system is normally deployed with an attached sensor on the physical object to activate the system.

6) AR and QR: AR and QR codes are other methods that museums apply for creating an interactive exhibit as an input technique for the system. The AR and QR codes offer a new way for visitors to interact with the system and a new way for museums to deliver scientific content.

7) Virtual Reality (VR): The VR exhibit offers museums delivery of an immersive experience for the visitors. Several of the museums in the study used VR HMD. It is often used as a passive form of telling a story which offers visitors to experience by watching a story. The VR HMD allows only one person at a time to have the experience and rarely provides the opportunity to share the experience with other visitors.

8) Other interfaces: the study found other interfaces in use, though not often deployed in the museums. For example, using bio personal information as an input of the system (brain interface, heart rate measure, etc.).

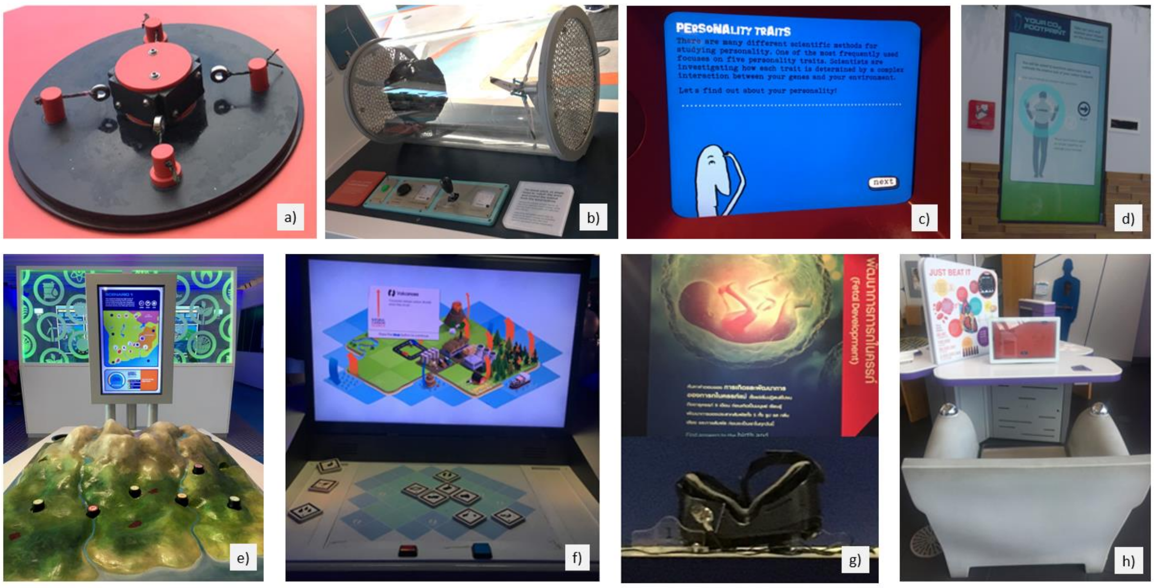

Figure 4.2 Example of interactive systems found in the study. a) Analogue system, b) Physical mechanics c) Touchscreen system, d) Gesture-based system, e) Tangible system, f) AR system, g) VR system, and h) a biometric interface.

The form of social interaction that is often found in the observation can be divided into four categories:

1) Single player without sharing experience: the exhibit allows only one visitor to have the experience at a time. Other visitors are unable to participate or observe what happens in the exhibit.

2) Single player other visitors can observe (co-presence): The exhibit is designed for one visitor to play at a time and allows other visitors to participate or observe what happens in that exhibit. This form of exhibit is normally found to use a screen to display content for other visitors.

3) Multi-player with co-player: the exhibit allows more than one visitor to play the exhibit together. For example, multi-touch screens allow visitors to explore the exhibit's content together, and the exhibit is designed for visitors to help each other to complete a mission. The exhibit is created with a tangible object that multiple players can easily interact with.

4) Multi-player with competition: the exhibit allows more than one visitor to play an exhibit and challenges the visitor to compete with another visitor.

In addition, the study examined the level of interaction an exhibit offers to visitors in the exhibit. The simplest one is an interactive exhibit that allows visitors to push a button to start playing a video or to start displaying a science phenomenon. The exhibits have various styles for telling stories and for interaction. This study found 16 styles of interactive design experiences. These styles are some of those mentioned in study of Kim et al. [105], which discussed the 20 types of playful experiences for educational game design. It found 12 styles, the same as discussed in study of Kim et al. [105], and eight other styles did not find in this study, including captivation, control, eroticism, nature, sadism, subversion, suffering, and thrill. In addition, it found four styles which did not mention in study of Kim et al. [105], including create and build, demonstrate a principle or explanation, roleplay, and quiz. The 16 styles found in this study are detailed as follows:

1) Exploration, an exhibit allows visitors to experience and gain knowledge by exploration, normally with unlimited time to explore. Visitors will spend their time exploring the content of the exhibit.

2) Discovery, an exhibit allows visitors to experience a storyline through the exhibit and intends visitors to discover some new knowledge or a new perspective.

3) Simulation, the exhibit simulates a situation for visitors to have an experience like they are in the situation, for example, the GPS car navigation simulator and the tractor smart farm simulation.

4) Completion, the exhibit gives a mission for the visitors with the intention of completing that mission. For example, an exhibit sets a mission for a visitor to help a patient suffering from lung disease.

5) Challenge, the exhibit challenges them to do something, gives a task for them to solve, and challenges them to test their ability. For example, the exhibit tests how fast the human body's nervous system responds to external stimuli and how fast that visitor can push a button that lights up.

6) Competition, the exhibit provides a feature allowing visitors to compete with competitors. The competitor can be another player, or game agent, or the visitor can compete with themselves to reach a goal of the exhibit.

7) Collaboration (in study of Kim et al. [105] called **Fellowship)**, the exhibit intends for visitors to play an exhibit together with another visitor. It intends for visitors to have social interaction and discussions about working and solving a problem together. It helps them exchange ideas and knowledge with visitors.

8) Create and build, the exhibit allows visitors to create or build a piece of work. Visitors will use their skills, along with the exhibit instructions, to create something.

9) Demonstrate a principle or explanation, the exhibit intends to show or describe science phenomena or a principle of science to visitors, or explain how the machine work. Some exhibits allow visitors to choose or adjust some variables that affect the result of a phenomenon or theory.

10) Role play, a narrative content style where a visitor pretends to be something in the story and experiences the exhibit's story like they were that thing.

11) Quiz, question and answer style where the exhibit asks questions and visitors find the correct answer. It often found use quiz to test the knowledge visitors get from the exhibit.

The following interaction styles intend to involve visitors' emotions. Sometimes, the exhibit only offers visitors to have fun, and sometimes the exhibit intends for visitors to feel an awareness of something.

12) Fantasy, this style of experience has the main purpose of inspiring visitors or making the exhibition environment more attractive. The exhibit creates a magical element, a magical experience for visitors, and bring visitors to an imagined world.

13) Relaxation, this style of interactive exhibit intends for visitors to have fun playing and makes them relaxed, more so than exhibits that deliver large amounts of information. For example, an exhibit might allow the visitors to dance on the interactive floor.

14) Sensation, an exhibit designed to involve visitors' emotions. This style is used to provoke visitors to be concerned about some issues and is intended to heighten visitors' awareness. For example, an exhibit about how difficult it is to make a decision to save human life when given two choices or an exhibit talking about climate change that shows how natural disaster kills fellow humans.

15) Sympathy, an exhibit influences visitors' emotions to care for someone who is suffering from some issue, has been affected by a bad situation, or has been affected by bad human behaviour. For instance, an exhibit on second-hand smoke shows children who do not smoke, but whose lungs have been badly affected by other people who smoke.

16) Expression, some exhibits invite players to express themselves through the exhibit. For example, the exhibit called Shadow forest [147] allows visitors to create and play with shadows. Visitors will create an animal by hand poses or another part of the body to express their imagination. Another exhibit allows players to choose clothes to express their style.

Figure 4.3 The experience style often found in the interactive exhibit: a) Exploration, b) Discovery, c) Simulation, d) Completion, e) Challenge f) Competition, g) Collaboration or Fellowship, h) Create and build, i) Demonstrate a principle or explanation, j) Role play, k) Quiz, l) Fantasy, m) Relaxation, n) Sensation, o) Sympathy, and p) Expression.

Common structure of interactive exhibits.

The study found a common structure across the interactive exhibits examined. *First*, an interactive exhibit has a page to attract visitors' attention. Normally, this will display the name of the exhibit and provide a sentence inviting visitors to touch and interact with the exhibit. *Second*, an exhibit has a page to explain what the exhibit is and the topic of the exhibit. *Third*, an exhibit has a page to explain how to play the exhibit. *Fourth*, an exhibit has a link that can go back to the home page. This last feature, an automatic system going back to the home page prompt, allows the next visitor to play in case the current visitor stops playing midway through the exhibit. Figure 4.4 shows the common structure of the interactive exhibit. a) show examples of exhibits using a game style in which normally found the flow of the system with a linear flow, step by step. At the end of the game, normally display the result or score. b) example structure of exhibit using exploration style allows a visitor to explore the content of the exhibit. It flows conduct like a hierarchy, including the main menu, content and sub-content. It can access forward and backwards through the hierarchy. c) an example structure of exhibit using quiz style. Its flow has a loop to display each question and answer and then show the statistical result and show more information to explain. They all have an automatic system back to the home page when the exhibit is idle for a long time.

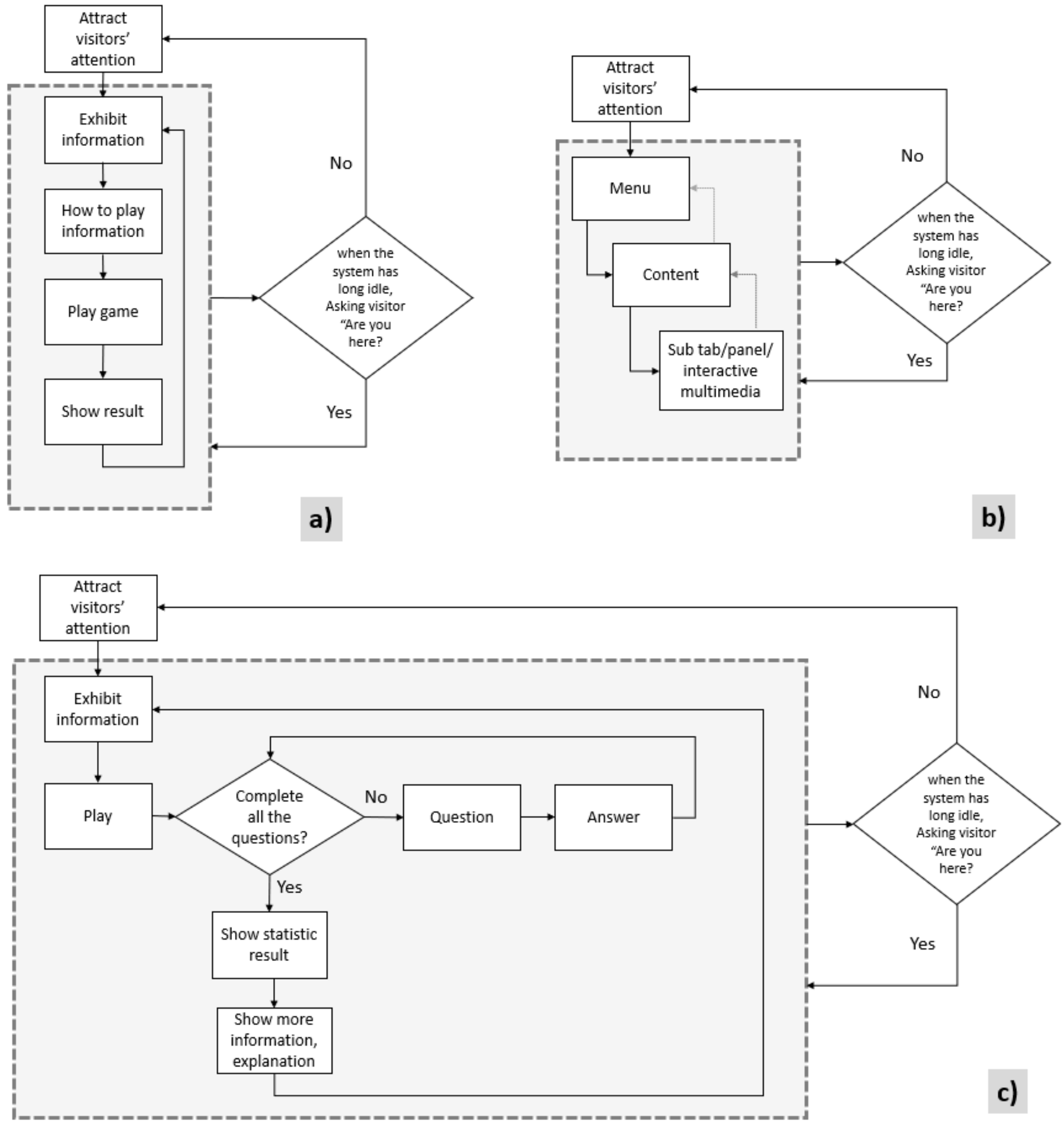

Figure 4.4 Examples of common structure of interactive exhibit include: a) Common structure of interactive exhibit using game style, b) Common structure of interactive exhibit using exploration information style, and c) Common structure of interactive using Quiz style.

4.3.2 Immersive Exhibit Observation

4.3.2.1 Study Aims

The study aims to investigate the immersive exhibits and immersive technology that museums currently use. The study tries to understand how museums apply immersive technology in their museum and how visitors behave during the play of those immersive exhibits. The study compares other immersive technologies with VR-HMD technology to determine the advantages and disadvantages of each technology.

4.3.2.2 Study Design

This study uses focused observation on particular installations which are based on immersive exhibits. The observation was conducted in four museums of the National Science Museum (NSM) in Thailand, including the Science Museum, Natural History Museum, Information Technology Museum and RAMA IX Museum as well as at the Science Museum in London.

The study has a day for the survey to choose a particular exhibit for the study and seven days for observation. The participants in this study are the visitors who visited the museum on the day of the observation period. The researcher plays the role of a visitor, standing around the exhibit or joining the activities with the visitors. With this technique, the researcher can observe visitors' behaviour more naturally and can listen to visitors' conversations: a visitor's speech or conversation between visitors. The participants also include the floor staff taking care of each exhibit.

The data are collected in terms of notetaking, photographing and asking museum floor staff to clarify some issues. The study's general aims are to find evidence of how the museum uses immersive technology, how visitors interact with the immersive technology and the issues involved in the use of immersive technology. The coding scheme for observation considered from general components of an exhibit and social interaction behaviour between visitors include: type of immersive technology, topic content, narrative, device and display, how to manage visitors, common conversation, and any exciting issues.

4.3.2.3 Results

Bitgood [21] discussed in his book about immersion experience is that refers to the feeling of being in a time and place, such as a historical period, animal habitat, geological formation, or space fight. And the focus of the immersion experience is on the experience rather than on formal learning. Bitgood discussed the immersion experience in the museum is more fun and exciting than a formal learning experience. And he stated that learning through an exhibit designed with an immersive experience is more memorable than a reading-only approach. Gilbert [68] discusses, from the point of view of museum professionals, three main reasons why museums use an immersive approach for their exhibitions. First, the immersive exhibition can attract people to their leisure time activity which can compete with other businesses. Second, they hold visitors' attention well and offer a memorable experience. Third, immersive exhibits deliver the content of the exhibit effectively. An example of an immersive exhibit technique is the diorama in the Natural History Museum, which shows habitat and creature behaviour. This method is still a useful approach to creating an exhibit that delivers an immersion experience to the audience. However, many digital techniques are available for museums to create an immersive experience for visitors throughout the exhibit.

The study found a variety of techniques that museums use to deliver an immersive experience to visitors, as follows:

1) 3D cinema, the 3D cinema has many techniques that allow the viewer to perceive the 3D virtual environment of the media. The various 3D display systems are discussed in [66]. In this case, the study uses a passive stereo system where viewers wear 3D glasses and use projectors to project light on a big screen. Visitors normally watch the media and rarely discuss it with other visitors.

2) Panoramic display screen, this system uses a half circle shape or bigger display screen and projectors to project media to the screen. The viewer is surrounded by the screen, immersing them in a 3D environment [197]. This display allows many viewers to watch media together. It is used in a passive form more than an interactive form of learning media.

3) Planetarium/full dome, this system generally displays stories about astronomy. Many projectors project light to cover half of a sphere. It offers the ability for many visitors to watch the media at the same time [69, 111]. Often, it displays a story of the planet, stars, galaxy, or space. Sometime, a staff-run planetarium tells the story and asked questions to interact with visitors.

4) Holographic, there are many techniques to create and display the 3D holographic effect [66, 164, 199]. The case study found museums apply the Pepper’s Ghost technique to display the 3D image floating in the air [164]. The hologram exhibits normally display 3D models of an artefact or tell a story to visitors. It can incorporate a 3D physical model and display a hologram on top of it. The holographic approach can be combined with an interactive component that allows visitors to interact with the 3D hologram. Many visitors can watch the holographic image at the same time.

5) 4D cinema, this system extended 3D cinema by adding another sense or real effect to viewers. The viewer will wear 3D glasses while watching the video and the physical effect is synchronized with the story. It makes viewers feel immersed with the real effect of the physical environment. For example, the case study, Desert life in dye zone exhibit produces wind and raindrops during the display of the story. The rain will drop when the story displays a rainy scene.

6) AR, a system that creates virtual objects or environment overlayed on top of the real physical world [47]. AR has many types and techniques and a variety of devices to access [47]. Generally, users access AR through a device which has a camera that can capture the real environment. An AR exhibit will show the virtual content on top of the real environment. Most of the AR exhibits are interactive media rather than passive media.

7) VR HMD, the virtual reality technology that uses a Head Mounted Display. The VR HMD creates a 3D virtual environment that immerses viewers in visuals and sound. The viewer wears a VR HMD during the experience with the exhibit. The system provides controllers that allow the viewer to interact with the content. Both passive and active exhibits were found using VR HMD. However, the passive exhibit that displays the story is more often found than interactive VR HMD exhibits. Visitors wear the HMD during the experience, with the exhibit limited to communicating with other visitors.

8) Simulator, similar to the simulators developed for training airline pilots. In this example, the machine enables the user to experience rotation, pitch and roll, which provides the sensation of flight. Combined with a screen that displays a virtual environment, this simulates flight experience. It makes people who play the simulator feel more immersed in the simulation [172]. The simulator can create a feeling of falling with gravity for the player. A variety of stories can be delivered by using a simulator.

9) Physical movement model, this technique builds a 3D replica physical model of objects or living things. And make its appearance realistic by adding some features for example adding mechanics to make its movement more realistic, adding sound, realistic skin/texture, or simulating an environment. For example, a dinosaur robot movement model.

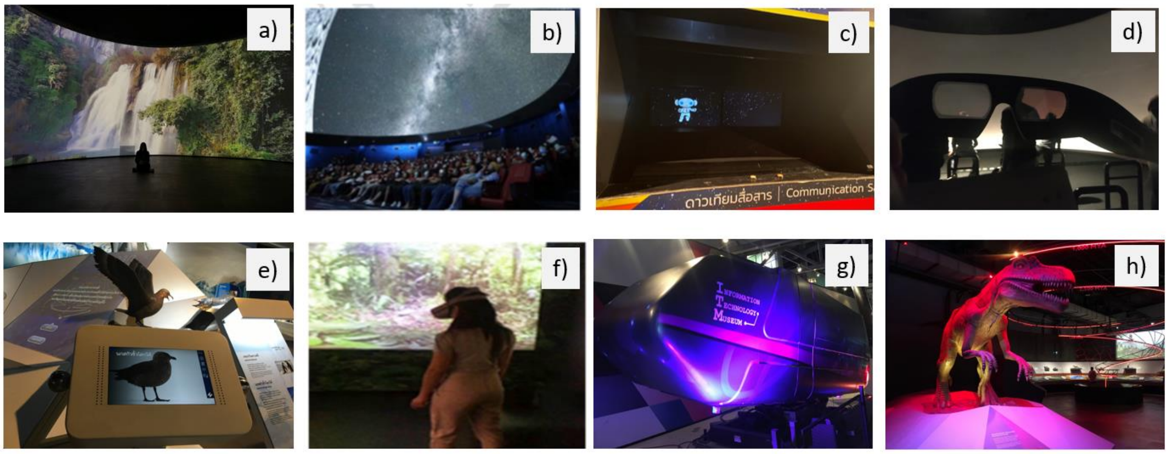

Figure 4.5 Examples of the immersive exhibit using in museums. a) Panoramic display screen, b) Planetarium/full dome, c) Holographic, d) 4D cinema, e) AR, f) VR HMD, g) Simulator, h) Physical movement model.

4.3.3 Using VR as an Exhibit Observation

4.3.3.1 Study Aims

The study intends to investigate how museums apply VR technology in the museum and to investigate the issues associated with using VR in the museum and identify ways to improve. And it also aims to investigate does VR need to improve the social interaction feature of an exhibit when used in the museum, thereby improving visitors' experience?

4.3.3.2 Study design

The observation selected particular exhibits to observe how the visitors interacted with them. The chosen exhibit is VR exhibits that displayed in each museum. The observer joined the activities, stood around the exhibit and asked floor staff to clarify issues when they arose. Nine VR exhibits were observed, including:

1) *The tropical forest VR experience* at Rama IX Museum. It is a video play of 11 minutes approximately length. The video tells a story about the tropical forest. The story starts from a top view and then moves down to the ground. The video shows the environment of the tropical forest. One local man in the tropical forest takes the viewer to many places to see his life in the forest. The end of the video shows a scene that brings the player up to the top view of the forest and displays a sentence to engage the viewer to think about the importance of the forest at the end of the story. The museum provides two Oculus Go

headsets and a big screen to show the pre-recorded video inside the VR for other visitors, but it is not synchronised with the video playing in VR HMD at that time. The staff holding the remote control does not allow visitors to use it; the staff will use the remote to select and start the video for the visitors.

2) *How to do a Royal rainmaking VR experience* at Rama IX Museum. This is a video play with an approximate length of 5.31 minutes, telling the story of an exhibit about the process of making the Royal rain (artificial rain). The video uses the first-person view and brings visitors to travel with aircraft. The video has two people: the pilot and the narrator. The narrator explains the method of every step of rainmaking, including the chemical formula of each substance. The museum provides six Oculus Go headsets (individual view) and six chairs for visitors to sit on when playing with the VR. The museum provides a screen that displays a video loop so that other visitors that stand surrounding the players can see the video. The video is the same story as the video in the VR HMD. The application in the VR has a system to reset the video back to the start point when the player takes the headset off.

The VR exhibits in 3-8 below are installed at a corner in the Information Technology (IT) Museum. All of them use a Samsung Oculus VR Headset. It is open for every visitor to experience by themselves.

3) *Fetal development VR exhibit* at the IT Museum. It is an exploration interaction style. The video tells the story and shows the characteristics of each organ in each system, e.g., sight and sound.

4) *Travel through the bloodstream VR experience* at IT Museum. The media brings the player on a trip through the bloodstream inside the human body. The content will pop up when the user selects each point in the model. It shows the 3D image, name, and structure of each molecule.

5) *In the eye of the animal VR experience* at IT Museum. It has an option for the user to select the kinds of animals that they want to have an experience with. It offers the user an experience like what each animal can see.

6) *The Space Adventure VR experience* at IT Museum. It is a video play telling a story about astronaut travel to space. It shows the environment in the space shuttle and space.

7) *The Jurassic world VR experience* at IT Museum. It is a video playing a story about dinosaurs. The animation in the scene seems to interact with the viewer.

8) *The Underwater world VR experience* at IT Museum. It is a video play in which the user can explore the vivid underwater world. It is full of various beautiful creatures, such as dolphins, turtles, etc.

9) *Space Descent VR experience* at Science Museum London. It is a video play telling the story of a pilot's mission. Viewers sit on a chair, and the movie brings the viewer inside a Soyuz capsule while a mission is returning to the earth from the International Space Station. The player plays the role of an assistant pilot bringing the space shuttle back home safely. The story creates a critical situation which happens in real life. The museum provides staff to explain how to play with the VR. The museum has a video that explains how to use the headset for visitors. The video also tells the story that visitors are going to have an experience.

The study also uses online data from the museums in the case study and other leading STEM museum sources, including the National History Museum in London, the Smithsonian National Museum of Natural History, the National Museum of Natural History in Paris, and the National Museum of Computing in the UK, this allows the researcher to better understand the form of using VR for the museum. Especially during the Covid pandemic, many museums created online media more intent on increasing accessibility for their visitors.

4.3.3.3 Results

However, VR can help museums deliver techno-scientific knowledge in various ways. The study found patterns that museums use VR to deliver knowledge. It groups based on where visitors can access the media: onsite at the museum or online, and how visitors continuity in having experience with the media: continue or discrete, including:

Onsite continuous VR experience: this pattern uses VR technology to tell a story to the visitor. Normally the museum sets up an area and provides a VR headset to each viewer. People enter the area and have a VR experience similar to watching a movie in the cinema. An example is the *Space Descent VR experience* with Tim Peake at Science Museum London [186] .

Onsite discrete VR experience: using VR as an exhibit. Visitors have a VR experience at the gallery, where VR is designed as a part of the exhibition. For example, the *tropical forest VR experience* at Rama 9 museum and the permanent exhibition called “Cabinet of Virtual Reality” at the National Museum of Natural History in Paris. It allows visitors to explore all 460 species of a creature via VR headset [38], and have this experience in the museum setting.

Online VR experience: an extended exhibit experience onsite at the museum that allows access to the experience everywhere, such as at home or school. For example, in the VR experience of the Natural History Museum, the player can explore the collection with Sir David Attenborough. The VR experience is available within the Sky VR app, so the visitor can access the experience everywhere by using the VR headset [156].

Online Virtual Museum: create a virtual environment that simulates the actual museum gallery for people to have the experience online. It delivers a sense of reality, similar to walking in a real physical museum, often called a virtual tour. Visitors can access the VR experience at their homes or everywhere online on many platforms [49] [225]. For example, the virtual museum tour of NSM, the virtual museum tour of the Smithsonian National Museum of Natural History [211] and the virtual museum tour of the National Museum of Computing [210]. The virtual museum makes the museum experience more accessible.

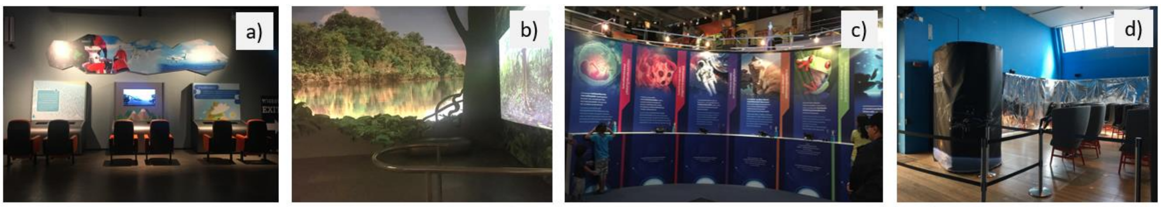

Figure 4.6 The example of VR exhibit in the case study. a) How to do Royal rainmaking VR experience, b) The tropical forest VR experience, c) the 6 VR experience at IT museum and d) Space Descent VR experience.

The observation found a time consumption pattern that influences the time a visitor occupies an exhibit. The estimated time that a visitor will finish experiencing a VR exhibit affects queue management found in the study. The time consumption of an exhibit can be considered in two ways: depending on media and depending on visitors.

1) Depending on media: the length of media influent on time a visitor finish experience with an exhibit. It found on exhibit uses a passive style of telling a story. The estimated time is dependent on the time to tell the story. For example, the Royal rain making VR exhibit at Rama 9 museum. Each visitor occupies the VR HMD until the end of the exhibit's story. Another pattern found in the general exhibit is that the exhibit uses an interaction style with defined time constraints. For example, in the *Design your power grid exhibit* at Science Museum London, the exhibit has a limit of time 180 seconds to complete a mission.

2) Depending on the visitor: visitor behaviour or ability influences the time a visitor finishes an exhibit's experience. It found with the exhibit uses an exploration interaction style. The estimated time depends on the visitor's interest in exploring the content, for instant, the *Travel through the Bloodstream VR experience* at the IT museum. Another pattern found in the general exhibit is the completion interaction style without a time limit. The time that a visitor occupies the exhibit depends on how fast the visitor can complete the exhibit's mission. For example, the *Let Make a Zoo from Bit and Byte exhibit* at the IT museum.

The study found five issues when using VR as an interactive exhibit: VR lacks social interaction, there is less support for family learning in the museum, lack of attraction power, hygiene concerns and weak queue management for crowded visitors. They will be discussed in more detail in the discussion section.

4.4 Discussion

This session will discuss the social context issue and practical constraints when using VR as an exhibit in a gallery based on the evidence found in the case study.

The social context is of key importance in creating an interactive exhibit, as suggested by many researchers. It is a core context for engaging museum visitors [54]. People tend to visit the museums together as a group: a family group, a group of students, or a group of friends. They usually share their thoughts and impressions via verbal communication [64]. Social interaction is particularly significant for a family that comes with their children. Young children need an adult to explain information that makes it difficult for them to understand an exhibit's message [20]. The observation found some issues that affect social interaction when using VR, as discussed below.

4.4.1 Communication and Discussion

Conversation is a kind of social interaction. The study found that, currently, using VR as an exhibit in museums does not facilitate visitors' communication or sharing of their experiences and impressions. It does not provide a mechanism for a parent or other adult who comes with children to interpret and explain information to their children. For example, during the observation of young children wearing a headset and interact with Fetal Development VR exhibit, their parent wanted to encourage them by asking the question, "What do you see?" Their children said, "I see a baby in the womb". The parent cannot see the situation, and what is happening inside the VR, so the parent cannot explain and continue to discuss with their children. The parent asked their children, "Do you see the blood vessel?" and their children did not respond to their parents. In this situation, the parent did not know the current situation that the children were experiencing. This not only happened to a family group, but it also with a group of students as well. While they wore a VR headset, they tried to talk and communicate and exchange impressions with their friends that stood around them (outside the VR world) or with their friend that wore a different VR headset (experiencing a different story). Examples of attempted conversations and attempts to share experience are: "It has a rocket below", "I see a shark", "What is it? I am in the middle of the ocean", "It is like the real ocean", "Beautiful very beautiful". They only say it out loud without anyone responding or discussing it with friends.

The single-player design for VR used in museums reduces social interaction between people. It does not help visitors exchange their knowledge and experience. Previous research has found that conversations between children and their parents or other people have an influence on children learning [97]. The open-ended Wh- question from the parent facilitates children to understand the scientific content of the exhibit or activity. Another study found evidence that when a parent has a conversation with children by asking Wh-questions, it makes children learn more about science than when parents do not ask a question. The Wh-question asks about their thoughts, such as why the exhibit happened like this, or "How does it work?", or asking for their feeling [78]. A child's question can indicate their curiosity and interest in the content of the exhibit, and their conversation can also indicate their understanding of the exhibit (a conversation is a tool for understanding learning) [78]. The conversation can be categorized into five groups, based on the level of understanding of scientific content shown, including perceptual talk, conceptual talk, connecting talk, strategic talk, and affective talk [59]. The perceptual talk describes the process of identifying and sharing what is important that children perceive from the exhibit, for example, identifying something, naming something, pointing out features of exhibits, and referring to things from an exhibit's label. Conceptual talk refers to talk indicating inference to interpret information from an exhibit. Connecting talk indicates the personal experience or knowledge connected with the exhibit. Strategic talk refers to talk that children mention how to use and manipulate an exhibit. Affective Talk refers to talk that children show an emotional response from the exhibit. Therefore, using VR in an exhibit with a single player will limit people's discussion for learning and understanding the scientific content of the exhibit.

4.4.2 Encouraging and Attracting Visitors' attention

When a museum tries using a VR headset, which is a personal device, only one person can access the device at a time. VR headsets is small compare with other exhibit in the same exhibition hall and content display inside the headset for only visitor who were the headset experience. One interesting finding is that the Rama 9 museum is trying to find an approach to improve visitors' experience, addressing this issue by providing a big screen which displays a video loop of the content in the VR headset for others visitor can see. The section that follows discusses why museums use big screens to extend experience from the headset and allows the museum to draw more attention to the exhibit.

1) Visibility: concerning the VR headset is small and not obvious to visitors. Enhancing the visibility of VR by putting a big screen along with the display helps increase the attractiveness of the exhibit to the visitor. It can be argued that VR is quite a new technology in the public space for visitors, so the technology itself can appeal to visitors' curiosity and encourage them to experience it. The new technology draws the attention of visitors who stop to play, curious to know the content hidden inside the VR headset. However, the effective footprint of the display is quite small compared with the big public space.

It was observed that the VR exhibits in the Rama IX Museum all used a big screen to make the exhibit more visible to visitors and stimulated visitors to pay more attention. At the same time, the museum puts the device inside a box; decreasing visibility for visitors to recognise the device. The VR at IT Museum increases the attractiveness of the exhibit by a panel that shows a picture of an example scene from a story inside the headset and puts the device in a location that is visible to visitors. Moreover, the exhibit display a big title name of the exhibit on the panel that makes the VR exhibit easy to see; this approach is similarly suggested in a study on how an interactive public system encourages people [139]. The study suggests that signage is effective at grabbing a passer-by visitor's attention.

Figure 4.7 Examples how museums put VR HMD in the gallery. a) The VR exhibit at the IT Museum and b) the VR exhibit at the Rama IX Museum.

In addition, this study found that the exhibits attract passers-by to pay more attention when a visitor is wearing the headset. Frequently, during play with the VR, people will act out according to the experience in the VR headset. The study found that most students were playing with the VR moving their hands in mid-air. Their behaviour seems strange for other visitors and causes them to pay attention. This phenomenon can be explained by triangulation in public space. The triangulation refers to process of an external stimulus provides a linkage between people who did not know each other before start to communicate to each other. It is the process in the public space that can bring people together and make them pleased to talk to each other. The external stimulus can be things, actions or activities that have a power like a magnet to bring people together [224] [77].

In short, setting up a big-screen display in parallel with the VR headset improves the visibility of the headset and can be a way to solve the problem of display blindness.

2) Supporting the honeypot effect: The honeypot effect outlines how people interact with an interactive system in a public space [229]. The honeypot represents something that attracts people in large numbers. Kelly et al. [103] describe three characteristics of a honeypot, including people congregating, visibility of people interacting with the technology, and shared experiences. The crowd of people nearby the technology is the signal telling people that something is happening. The visibility of user interaction with the system allows another to observe and learn how to interact with the interactive system. The honeypot effect supports the audience in sharing the experience with the player. Undoubtedly, the reason why an exhibit should display the content in the VR headset on the big screen is that other people are able to know the activities that can stimulate the honeypot effect.

In addition, related to the honeypot effect is how being able to view the VR content on a big screen may change the role of the visitor. The role of a visitor can be defined by six roles: a passer-by, a bystander, an audience member, a participant, an actor, and a dropout [229]. A visitor's role may change, and social interaction is an influence on visitors' transition between roles. The bystander is engaged in the exhibit via the output of the system: visuals, sounds, or things that can be touched. If bystanders are interested in the exhibit, they will start reading the instructions, observing or talking with other people. Another idea is that the visibility of the content in the large display engages visitors to start social interaction and sparks conversation between visitors [139].

To sum up, the big screen display, in combination with the VR, stimulates a honeypot effect that maintains the exhibit' s attractiveness.

3) Increase the number of visitors having an experience: VR-HMD is a single-user device (one person can access it at a time) and its use in a large public space can be ineffective at delivering an experience to many people at the same time. Having a big screen beside the VR headset will increase the number of people who have an experience from the exhibit. For example, one visitor plays, and another observes the exhibit. Only one player plays an exhibit at a time, but many people who surround the exhibit can have an experience by observing the current player interact with the exhibit. In the same way, some people prefer to learn by watching other people do [229]. Generally, a student visits the museum with a large group of their classmates. Providing many devices and giving an opportunity to all visitors a chance to access the device at the same time might be impossible, or, at least, time consuming. Providing an alternative way that visitors can have some experience and learn the core scientific content of the exhibit is a good alternative. One study pointed out that students often share their experiences with their friends [190]. The observation here found that many visitors outside the VR environment want to interact with the people who are wearing the VR headset, for example, the sister wants to talk with her brother, who is wearing the device. Therefore, providing a big screen that shows the activity inside the VR headset is a good way to extend the experience of a VR headset such that it may be delivered to a large audience.

However, the observation here suggests that many museums did not synchronise activity in the VR headset display with the big screen, opting instead to display a pre-recorded video from a previous session. Thus, other visitors that stand surrounding the exhibit do not have a chance to share the experience with the player. On the other hand, the Rama 9 museum tries to increase the number of visitors that can have an experience by providing many devices (six VR headsets at the Royal rainmaking exhibit). There are still unanswered questions about which solution is better for emphasising social interaction and sharing experiences when designing an exhibit for learning in a museum. First, a displayed video loop without synchronising with the headset with an increased number of devices. Second, display activities on the screen that are synchronised with the content in the VR headset, with one player and many visitors observing. And third, display content that synchronises with the VR headset and another visitor can interact with the player wearing the device.

4.4.3 The Practical Challenge of Designing a Good User Experience

Museums are popular places for schools to bring their students to visit together simultaneously, especially on the school day (from Tuesday until Friday). Normally, a school trip will see students arrive at the museum at the same time, making the museum crowded with visitors in the gallery. The museum not only supports crowds of students but also prepares to service groups of families who come together on weekends and holidays as well. Usually, in a crowded situation, many people wait in the queue to have an experience with one exhibit that uses a device where only one person can access the device at a time. Clearly, the VR headset is a single-user device, and it has repeated use by many people. The visitors will feel good using the headset if the VR is hygienic. This section will discuss how to create a pleasant experience by balancing the practical problem.

1) Visitors' experience and content design: the observation found many people waiting in line to have an experience with VR. Importantly, the balance between what makes a good user experience and the practical constraints in the real-world situation should be considered when designing an exhibit using VR. It must consider how to create an experience that can communicate all the content to visitors while dealing with a crowd of people who desire to play with the exhibit at the same time. Findings from these studies suggest that the length of the media can affect user experience in many ways. For example, in the Tropical Forest exhibit at the Rama 9 Museum, the length of the movie is around 11 minutes. The staff on the floor must manage the crowd to make an equal chance for visitors to have an experience with the exhibit. In practice on the floor, the museum staff choose to give a limited time for each visitor to play. The staff said when the Tropical Forest exhibit has many visitors waiting to play the VR exhibit, they [64] will allow a visitor to play for approximately 3 minutes per person. Thus, the visitor cannot reach the aim or the message that the designer put at the end of the story.

Figure 4.8 Crowd of visitors and people waiting to having an experience from the exhibit. a) many VR-HMD provide for the Royal rain making exhibit. b) one VR-HMD device per one topic provide for the VR experience corner at IT museum. c) one VR-HMD provide for the Topical Forest exhibit.

Automatic playback video is one issue found in the study. An interactive feature that can automatically go back to the start point is a normal mechanism that the interactive designer adds to the system. It intends to help the museum manage the exhibit prompt for the next visitor to play in case of the previous user drops out in the middle of the story. In the real situation of the case study on the *How to do Royal rain-making* exhibit, the UI design does not have a menu for the user to select, and the user plays with the VR without the controller. The strategy to control the interactive playback and return to the start point is that if visitors take the headset off from their head for a second, the video will go back to the start point again. In the crowded situation, the study found that many children took the headset off very often before they finished the experience, so it will bring the video back to the beginning of the story over and over. The player cannot continue the story from the point before they take the headset off. This situation results in a user needing longer than usual to finish the experience. It is a challenge for museums to design UI for a VR experience with visitors who are unfamiliar with using the controller and how to manage the removal of the device.

2) User experience design versus device constraints: VR is a 3D recreated image experience. In the VR environment, users have more degrees of freedom to explore the content than in a 2D environment, like an application on a desktop screen. In designing an experience for VR, the activity in the VR environment affects how the player behaves in the physical world. For example, when an experience is designed allowing players to move by walking around a scene, during this VR experience the player will walk around in the physical area. Or, if an experience is designed so that people can explore many places using a controller to navigate, while in the physical world, visitors will stand at one point and use the controller to navigate themselves through the scene. User experience design influences how to choose the type of device, for example, a wired or wireless VR headset [71]. The museums that form the basis of these case studies used Oculus Go and Samsung Gear VR. In both cases, the HMD is a wireless device, and the user freely moves their head and body without obstruction by a wire cable. Using wireless reduces the risk of movement, reduce risk of tripping or tangling with the cables. On the other hand, the device quickly runs out of battery in two hours. In a crowded situation, on the day of the observation, the staff on the museum floor had to recharge the device, and the device took a long time to charge fully, more than 2 hours. The exhibit was closed while waiting for the device to be ready to use again.

The study also found that the user experience design is related to the space that the museum provides for the visitors to play with the exhibit. In the Tropical Forest exhibit, the museum provides a controlled area for the visitors during the play of the exhibit, but in reality, people did not use VR headsets inside that area. Instead, they stood outside in front of the screen, where visitors can freely walk and look around the scene. Staff said the reason the practical situation differed from the interactive designer's wishes is that the visitors want to wear the headset close to their parents or friends. In fact, the Tropical Forest video gives the freedom to explore the content and allows the player to walk around the scene. One of the suggestions for designing a VR experience for use in a museum in a limited area should include limited visitor's movement by setting the viewpoint in the VR scene, for example, in [181] design experience by using gaze from a fixed point technique to prevent the moment of visitor in the limited area and reduce health and safety problems.

Many people are unfamiliar with VR technology. One study reported that 62 per cent of the participants had never experienced using a VR headset before [181]. The risk associated with visitor movement in the public space can be minimised by using a controller to navigate in the VR instead of using body movement in the physical space. However, using the controller is quite difficult for people who are unfamiliar, and the controller needs power as well.

It was observed that many visitors do not use an interactive feature that has been created for the exhibit named Travel Through the Bloodstream Inside the Human Body. The researcher heard the museum staff teach children using the headset to interact with the content. The touchpad on the headset is difficult for visitors to recognise, especially people who are new to the VR experience. Some research tries to solve this problem by using another technique to interact with the content in VR, such as using gaze-based interaction [181] or using freehand interaction [137].

3) Audience experience versus health and safety: health and safety in the use of VR are widely discussed, and a the issue of motion sickness, described by Hale and Stanney [79], should be considered when using VR headsets. This study did not find or hear reports from the visitors that they felt unwell after having an experience with VR. However, the study found some issues that should be considered when using VR headsets as an exhibit in public spaces. Using a VR headset, users must wear a headset which is in close contact with their face. If the headset is used for one person, one can avoid thinking about the hygienic issues. However, in a real-world situation, the headset sees repeated use from one visitor to another. In the case study, the museums do not have a method to deal with this problem. If a user is concerned about wearing a dirty VR headset, they may be uncomfortable using the headset, which may prevent them from playing with the exhibit. One solution is using a disposable VR sanitary eye mask for the VR headset. In this case, the user might feel uncomfortable or feel something strange over their face, and the museum must provide an eye mask for the visitor, which incurs an extra cost to support many visitors per day. Another possible resolution is to change the material of the face-covering on the VR headset to a material that enables cleaning. An example of a solution to these problems is introduced in Schofield et al.'s research. They built a specific HMD for the project to solve the problem of hygiene and provide an extended long life of the batteries. However, the new design headset has problems with the mobile device's heating and audio quality [181].

Another issue that the museum should consider is designing an exhibit by using VR technology in terms of user experience. The museums should have a minimum age for children to be able to access the VR. In the study, the researcher saw one visitor who was very young; he was around 3-4 years old. He cried and felt scared after playing with the VR. His mother reported to the researcher that this also happened in a 360-degree view room as well, where he felt scared and cried while watching the video in the 360-degree room. Moreover, the VR headset is quite big compared with the size of young children’s head, which can cause the experience to be awkward.

4.5 Conclusion

This chapter summarises the result of the museum observation. The observational study was conducted with three main purposes.

First, the general museum observation focussed on studying the character of the interactive exhibits in the museum context and visitors’ behaviour using the exhibits. The results found 7 exhibit systems often used in museums, 4 social interaction styles, and 16 styles of interactive experience. The results found common characteristics of the interactive exhibits system which include attraction page, information page, content, a link to go back to the home page, and an automatic mechanism to return to the attraction page.

Second, the immersive exhibit observation focuses on the study of immersive technology, a technique that museums use to deliver an immersive experience to visitors. It aims to compare and contrast those technologies with the VR HMD technique and study the characteristics and visitors’ behaviour experienced with the exhibit. It found at least 9 techniques that museums use for delivering immersive experience, including 3D cinema, Panoramic display screen, Planetarium/full dome, Holographic, 4D cinema, AR, VR HMD, Simulator, Physical movement model.

Third, the observation focussed on studying how museums use VR technology to answer the question of whether the museum needs to improve social interaction for users while using VR, in order to further enhance visitors’ experience. The case study had 9 VR exhibits to observe. The study found three main issues that affect user experience.

1) *Communication and discussion*. The result found that currently, using VR as an exhibit in museums does not facilitate visitors’ communication, sharing of their experience and impressions. For example, young children need an adult to explain techno-scientific content that is difficult for them to understand. Additionally, if a group of friends visits the museum together, they typically want to share the experience with their friends.

2) *Encouraging and attracting visitors’ attention*. One interesting finding is that museums are trying to find an approach to improve the visitors’ experience by providing a

big screen which displays a video loop of the content in the VR headset. The museum uses a big screen to extend the experience beyond the headset and to draw more attention to it. This is accomplished by increasing visibility, supporting the honeypot effect, and increasing the number of visitors sharing an experience.

3) *The practical challenge of designing a good user experience*. The challenge is to design a good user experience that deals with the issue of using VR in a real museum environment. The three aspects that should be considered are visitor experience and content design, user experience design versus device constraints, and audience experience versus health and safety. In addition, to deal with crowds of people in the gallery, the design should balance the length of media and queue management to provide a good experience for the visitor. The design should consider an interaction that is designed for the media required and a device that is suitable for use in a real situation, especially a novel technology that people are unfamiliar interacting with. This unfamiliarity can prevent the visitor from using the interactive exhibit. Using VR as an exhibit, the locomotion design has many factors in choosing a technique: using a controller adds the need to deal with removing and managing the device; using movement of the body must deal with the size of the media in the VE and the size of the physical space; the degree of freedom design in media and gallery space should be similar, and the design of the user experience when using a mobile VR headset must deal with battery management. Healthy and safety are essential for museums to provide good service. Hygiene should be considered when using a VR headset, and the museum should have a rule for young children regarding access to a VR experience.

In short, VR has a weak point in supporting social interaction between visitors in comparison with other immersive technology. This should be considered when choosing VR to design an exhibit. The following chapter will explore the solution how to provide social interaction between visitors when using VR to develop an exhibit.

Chapter 5 Alternative Design for an Interactive Exhibit Study

5.1 Introduction

One challenge for exhibit designers is choosing the most effective technology for creating an exhibit. The character of the museums' interactive exhibits is edutainment style, which provides learning content and entertains visitors, simultaneously learning for a fun experience [153]. A variety of technologies are possible to create an exhibit, and this challenges the exhibit designer in choosing the most effective technology. A different technology might impact user experience differently. For instance, the diorama is an immersive exhibit form in a museum [21] which can use VR technology instead. However, VR HMD has a weak point in that it decreases social interaction between visitors, as found from the museum observation mentioned in Chapter 4. However, VR allows museums to be more flexible in delivering content to visitors and learning through an immersive experience like VR technology offers visitors more capability to remember than the reading approach [68].

This study addresses research aim two by investigating the alternative technologies which make it possible to create an interactive exhibit in the museum context. This experiment conducts an empirical study to compare user experience between three technologies: tangible, gesture and VR. The three exhibits differ in terms of manipulation and input device but deliver the same scientific content, narrative style, and activities. It aims to study factors influencing user experience when using different types of technology. The results will be used as a guideline for choosing technology in the framework.

This chapter starts with section 5.2, outlining the goals of this study. Next, section 5.3 explains this study's design, including system design, content and narrative story, system implementation, participants, measurement, and procedure. Section 5.4 then reports the results found from this study, both quantitative and qualitative. Next, section 5.5 discusses the interpretation of what this experiment found and suggests designing a VR exhibit. And lastly, section 5.6, summarises the information of this study.

5.2 Study Goals

This study aims to investigate how the user experience differs across the alternative technologies for creating an exhibit: tangible-based interface, gesture-based interface, and VR. The difference in technology might make user experience different in exhibit attractiveness, user engagement, and learning outcomes. In addition, it investigates factors that should be considered when selecting a technology to create a new interactive exhibit for learning in STEM museums.

Research question

The research questions for this experiment are **RQ1**: how does the choice of technology to create an exhibit affect visitors' experience? **RQ2**: what are the factors that should be considered when choosing technology?

Hypotheses

There are two hypotheses that this experiment intends to investigate.

H1: VR offer higher user experience quality than using a tangible-based interface, a gestures-based interface, and a VR interface.

H2: VR has a higher holding power than gesture-based and tangible-based interfaces.

Variables

The variables for this study are:

Independent variables: the three technologies interface include a tangible-based interface, a gestures-based interface, and a VR interface.

Dependent variables: six factors of user experience: attractiveness, perspicuity, efficiency, dependability, stimulation, novelty, and holding power.

Control variables: the topic of the content, the narrative content, and the activities of the exhibit.

5.3 Study Design

5.3.1 System Design

This study selects three alternative technologies to focus on different features for comparison and contrast with VR exhibits. The interactive museums can be hands-on interactive, which allows visitors to touch objects to have the experience and gain an understanding. In addition, it can be interactive multimedia which allows interaction with multimedia control by a computer with a touch screen, push-button, mouse, and keyboard. In contrast, a hands-off interaction did not allow visitors to touch the object [171]. Therefore, this study focuses on hand-on interactive exhibits. The three technologies include a gestures-based interface, a tangible-based interface, and VR.

In a gesture-based interface, players interact with the exhibit without touching the objects and mainly use the player's body as an input device. Gesture-based interfaces enhance the experience through body interaction with the world, and it is grounded on embodiment theory, that players perceive and understand things through their body movement [34]. Gesture-based is a natural user interface, and it allows players to naturally interact with the exhibit as humans interact with the actual physical world [192, pp. 252-255].

In contrast, a tangible-based interface allows visitors to touch the exhibit's objects. It is a simple interface that visitors are familiar with and naturally interact with the object by hand [135]. In addition, it allows visitors to interact socially and collaborate with other visitors [222]. One of the weak points of tangible is the limited display of such content. It can be enhanced by combining concreteness of the physical object and digital representation, which helps display more information and helps players understand difficult content [214].

While VR is a dominant delivery of an immersive experience to users, its advantage for education is that it allows learners to immerse in the learning content created in a 3D virtual environment [30]. It enhances learners' ability to learn with more enjoyment and it concentrate more on media than non-immersive, like video display [132]. Although VR is not a tangible-based interface, the controller offers players the ability to feel tangible when interacting with objects in the virtual environment (VE) [173]. Many people are unfamiliar with using the VR controller, but the experience can be enhanced by making the controller more natural map onto hand movement in the VE [138, 173] which is consistent with that found in study of McEwan et al. [138], players are more familiar with an incomplete tangible mapping such as VR controller than kinesics natural mapping like gesture.

Undoubtedly, VR has many positive aspects. It is able to replace the sense of touch of a tangible-based interface by the controller, and the VR system can be more intuitive with the natural mapping of the controller. However, to access VR, the most common use is via VR HMD, which makes VR lack support for sharing experiences between visitors, which is crucial for learning in museums. Furthermore, VR HMD players often suffer from motion sickness and hygiene issues. So, this experiment chose these three technologies to investigate: VR, Gesture-based interface, and tangible-based interface.

The three exhibits created based on these technologies deliver the same scientific content about biotoxin in nature. The tangible is the master model that the researcher originally created during a project in a previous study. The other two exhibits are newly created and extend from the tangible-based interface. The system has two main parts. The first part is an interactive box that provides a test area representing eat, smell, touch, feedback with sound and light, and animation feedback on screen. The player will bring an object model of a mushroom or frog to test a result on the test area. Part 2 is a box with six mushroom models and two frog models inside the box. The box decorates the forest environment scene. The three exhibits are shown in figure 5.1. The detail of each exhibit is described as follows:

1) Exhibit 1: Gesture-based interface: UI01-gesture, players move their hand over the Leap Motion sensor to interact with the objects displayed on a monitor screen. The player closes their palm to pick up an object and opens their palm to release an object on target. A computer monitor shows all the system's feedback, including animation, sound, and light colour.

2) Exhibit 2: Tangible-based interface: UI02-tangible, players interact with the exhibit by using their hands to pick up a physical model in the box and place it in a test area on the interactive box. The interactive box will present sound and colour feedback, and the animation will show on a PC monitor.

3) Exhibit 3: VR-based interface: UI03-VR, players wear a VR HMD and use VR controllers to interact with the system. All objects in the system are created in VE: the interactive box, the box with mushroom and frog models, and animation feedback. The player uses a controller to pick up a virtual model in the virtual box by pressing the Trigger button, and moves the virtual object and drops it into a test target on the virtual interactive box. The light-up colour will show on the virtual interactive box and simultaneously display animation feedback in front of the player's view in the VE.

a)

b)

c)

Figure 5.1 Examples of interactive exhibit used in the study. a) Exhibit 1: Gesture-based interface b) Exhibit 2: Tangible-based interface c) Exhibit 3: VR (reprinted from Ref. [163]).

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5.3.2 Content and Narrative Story

The exhibit educates players on scientific content about biotoxin plants and animals in nature. The exhibit did not set a mission for players to accomplish and allowed players to explore the exhibit without limitation of time. The story showed six various types of mushroom models representing poisonous mushrooms and edible mushrooms. The story shows two types of frogs, one normal frog and one poisonous frog. The interactive box has three testing areas representing human action: eat, touch, and smell. The exhibit shows the reaction of the human body after humans eat, touch, and smell the poisonous things in nature. The 24 different animations were displayed one by one on a screen according to the condition that the player brings a mushroom or frog model test to the testing area. The animation showed how the poisonous thing affects human organs and showed the scientific name and common name of the mushroom/frog that the player brings to test. In addition to the animation, sound and a colour light up display on the interactive board warn about the dangers of that poisonous thing. The colour light up has three colours: red means dangerous, green means normal, and yellow means be careful. The warning sound has three different sounds: the three-tone beeps mean negative, the single beep means positive, and none means in between. All feedback: animation, sound, and colour light up were shown simultaneously. Figure 5.2 shows an example of the system feedback.

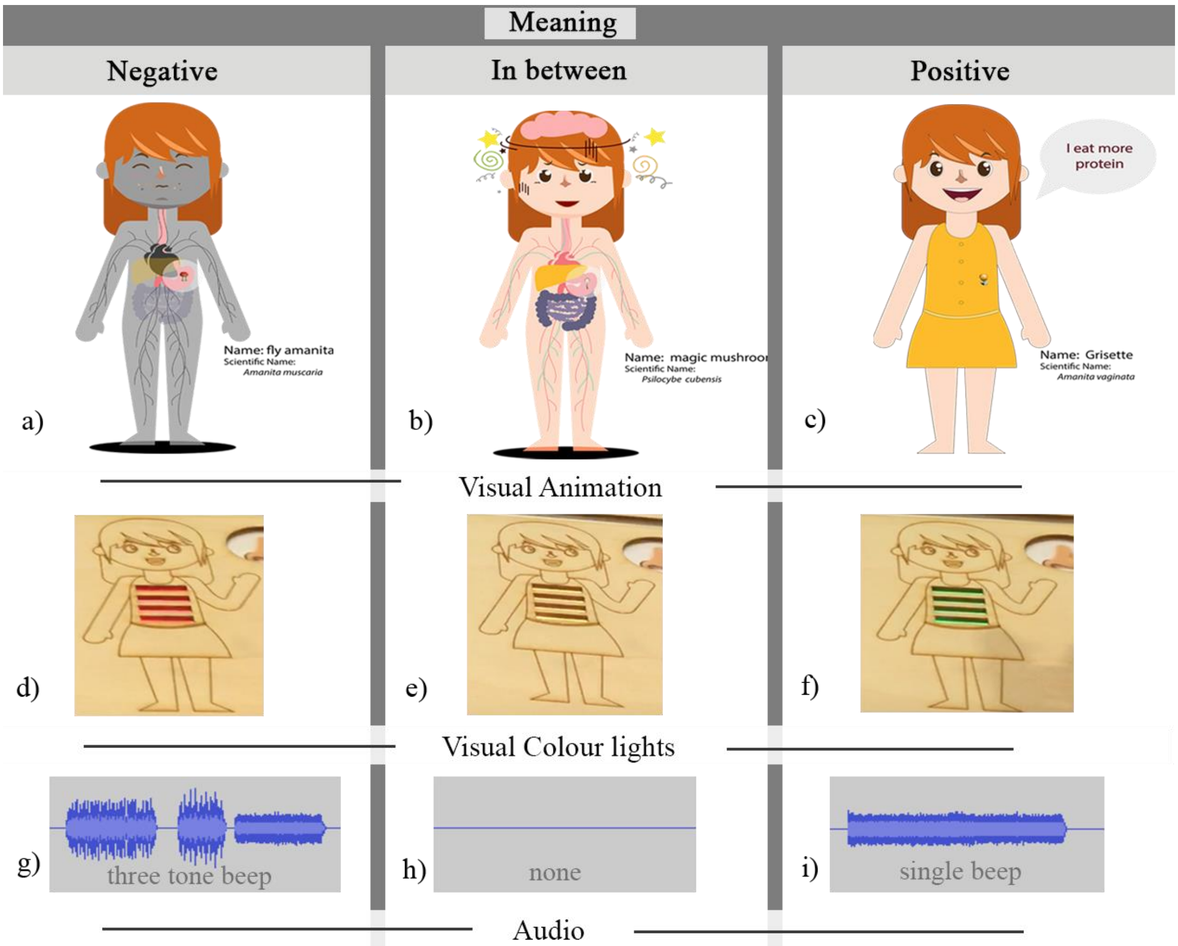


Figure 5.2 Example of feedback on interactive exhibit (reprinted from Ref. [163]).

5.3.3 System Implementation

The three exhibits are developed with different techniques. The details are as follows:

1) Exhibit 1: Gesture-based interface: Unity software is the main software used to develop the game. The Leap Motion is an input sensor device of the system. It connects via a USB port to a computer. It is used to detect the player's palm pose. All the physical models of the tangible interface are recreated into the virtual 3D models by Blender software and imported into Unity. The pose of the player's palm uses a simple rig to represent on the screen. All the player actions, feedback and forest environment are displayed on the screen.

2) Exhibit 2: Tangible-based interface: the system has two parts: a digital interactive play box (digital part) and a box to show the mushroom/frog models (physical part). The digital interactive play box use microcontroller to implement, which is composed of two Arduino Mega 2560 boards and five Arduino Nano connect to RC522 RFID 13.56 MHz module (RFID reader). It connects to a PC via a USB Serial port to transfer data. LED strips are used to light up show status on the board, and Piezo Buzzer is used to play sound for the system. The physical part is a decorated box with the forest scene and mushroom/frog models placed inside the box. The model of the mushroom and frog are attached by NFC tag underneath each model. The mushroom models are sculpted with polymer clay, and a 3D printer created the frog models. The animation feedback display on a computer screen is developed by Unity software.

3) Exhibit 3: VR-based interface: the system used an HTC VIVE VR HMD, and the player used VR controllers to interact with the system. The Unity software is the main software used to develop the game. All the physical objects of the tangible interface are recreated in the VE. In the VE the interactive playbox and the box of mushroom/frog models on a table were all created. All the feedback is created in the VE. The animation was displayed in front of the player view.

5.3.4 Participants

This experiment uses a within-group study by recruiting, via email invitation, 30 participants aged over 18 years. The participants mixed various backgrounds and knowledge.

5.3.4.1 Participants Demographic

This study has 31 participants joined experiment, 17 male and 13 female and one other gender. Twenty-two people reported having visited STEM museums, 18 people had never used a gesture-based interface before, 22 people had never used a tangible-based interface before, and 22 had ever used VR. In addition, 21 people reported they were unfamiliar with the exhibit content biotoxin in nature. Figure show the participants' background information.

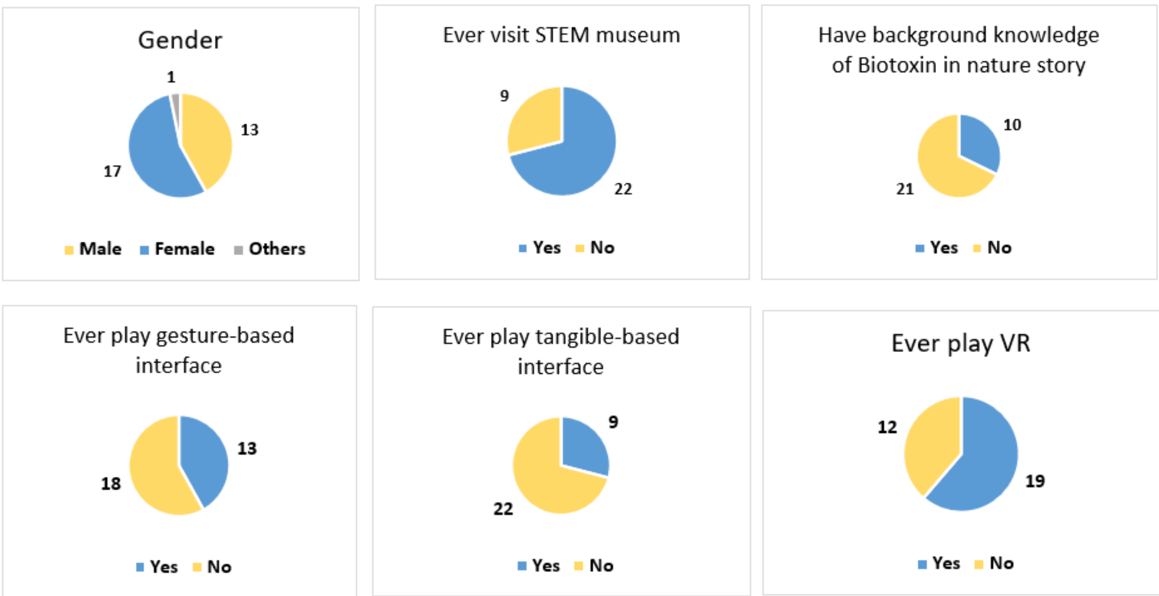


Figure 5.3 Participants' background information.

5.3.5 Measurement

The experiment uses quantitative and qualitative data to answer the hypotheses and research questions. The experiment measures user experience and the holding power of the exhibit. Measuring the user experience dimension of an exhibit in a museum has been a suggestion from many researchers [121, 129, 152, 228] but they are not relevant to this study's aim, so this experiment decided to use a standard user experience questionnaire instead [86]. The User Experience Questionnaire has 26 questions which it divides into six dimensions: attractiveness, perspicuity, efficiency, dependability, stimulation, and novelty. It covers measuring both pragmatic quality and hedonic quality. The holding power indicates how the exhibit holds the player's interest. If the player spends more time on the exhibit, they will receive more information from the exhibit, indicating that the exhibit better engages players to play. It is measured by the time that the player plays the exhibit. The qualitative measurement uses semi-structured interviews after finishing their experience with each exhibit and video recording to find issues of each interactive exhibit.

5.3.6 Procedure

The three exhibits are set up in a room prompt for the participant before arriving. Figure 5.3 shows an example of devices and room setup. The researcher explains the study to the participant, and the participant signs a consent form and does general background information on the questionnaire. Then, the participant is assigned a sequence to play each interactive exhibit equally randomly by using Latin Square. After the participant finishes experiencing each interactive exhibit, they complete the UEQ and have a short interview about their experience with the exhibit. After the participant has experienced the three interactive exhibits, they are interviewed about the overall experience. The experiment takes around 30-40 minutes.

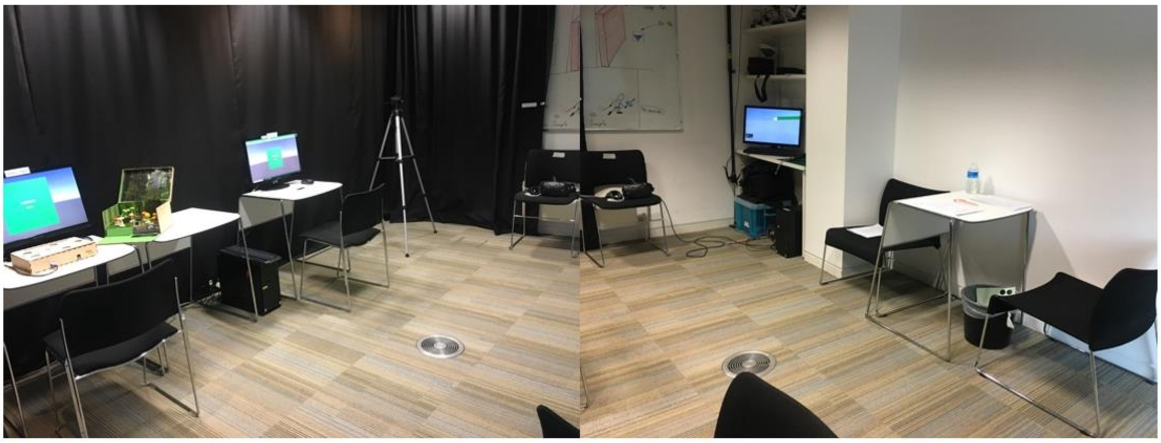


Figure 5.4 The room and set up of the experiment.

5.4 Result

5.4.1 Overall User Experience of Each Exhibit

Each item in the UEQ was transferred into a scale of +3 to -3, as the suggested in [86], in which +3 is a positive value, and -3 is a negative value. The results are divided into three categories: negative evaluation (value < -0.8), neutral evaluation (value between -0.80 to 0.8), and positive evaluation (value > 0.8).

1) Exhibit 1: gesture-based interface: the results of the gesture-based interface obtained lower scores than the tangible exhibit and the VR exhibit. The results show 11 items receive positive feedback, and 15 items receive negative feedback. The top five highest scores include: conservative/innovative (M = 1.68, SD = 1.14), dull/creative (M = 1.68, SD = 1.17), conventional/inventive (M = 1.58, SD = 0.96), not understandable/understandable (M = 1.45, SD =1.92), unattractive/attractive (M = 1.32, SD = 1.08). The three lowest scores include: fast/slow (M= -0.52, SD=1.46), obstructive (M= -0.26, SD = 1.44), and inefficient/efficient (M= -0.19, SD = 1.78).

2) Exhibit 2: tangible-based interface: six items of the tangible exhibit obtained a higher score than the VR exhibit, including not understandable/understandable (M = 1.97, SD = 1.20), complicated/easy (M = 2.23, SD = 0.84), unpleasant/pleasant (M = 1.81, SD = 1.08), secure/not secure (M = 1.68, SD = 1.40), clear/confusing (M = 1.839, SD = 1.463), friendly/unfriendly (M = 2.39, SD = 0.84). The tangible exhibit receives a higher score on unfriendly/friendly than other items, where M= 2.39 and SD = 0.84. Only two items received neutral evaluation: usual/leading edge (M = 0.45, SD = 1.52) and slow/fast (M = 0.23, SD = 1.54).

3) Exhibit 3: VR interface: the results of the VR exhibit receive only one item: neutral evaluation. It is slow/fast (M = 0.74, SD = 1.59). Almost all items in the VR exhibit got a higher score than the tangible exhibit, except six items mentioned in the tangible-based got a score lower than the tangible exhibit. The top five highest mean values are unfriendly/friendly (M = 2.35, SD = 0.71), difficult to learn/easy to learn (M = 2.19, SD = 0.91), cluttered/organized (M = 2.13, SD = 1.12), annoying/enjoyable (M = 2.06, SD = 1.00), and inferior/valuable (M = 2.06, SD = 1.03).

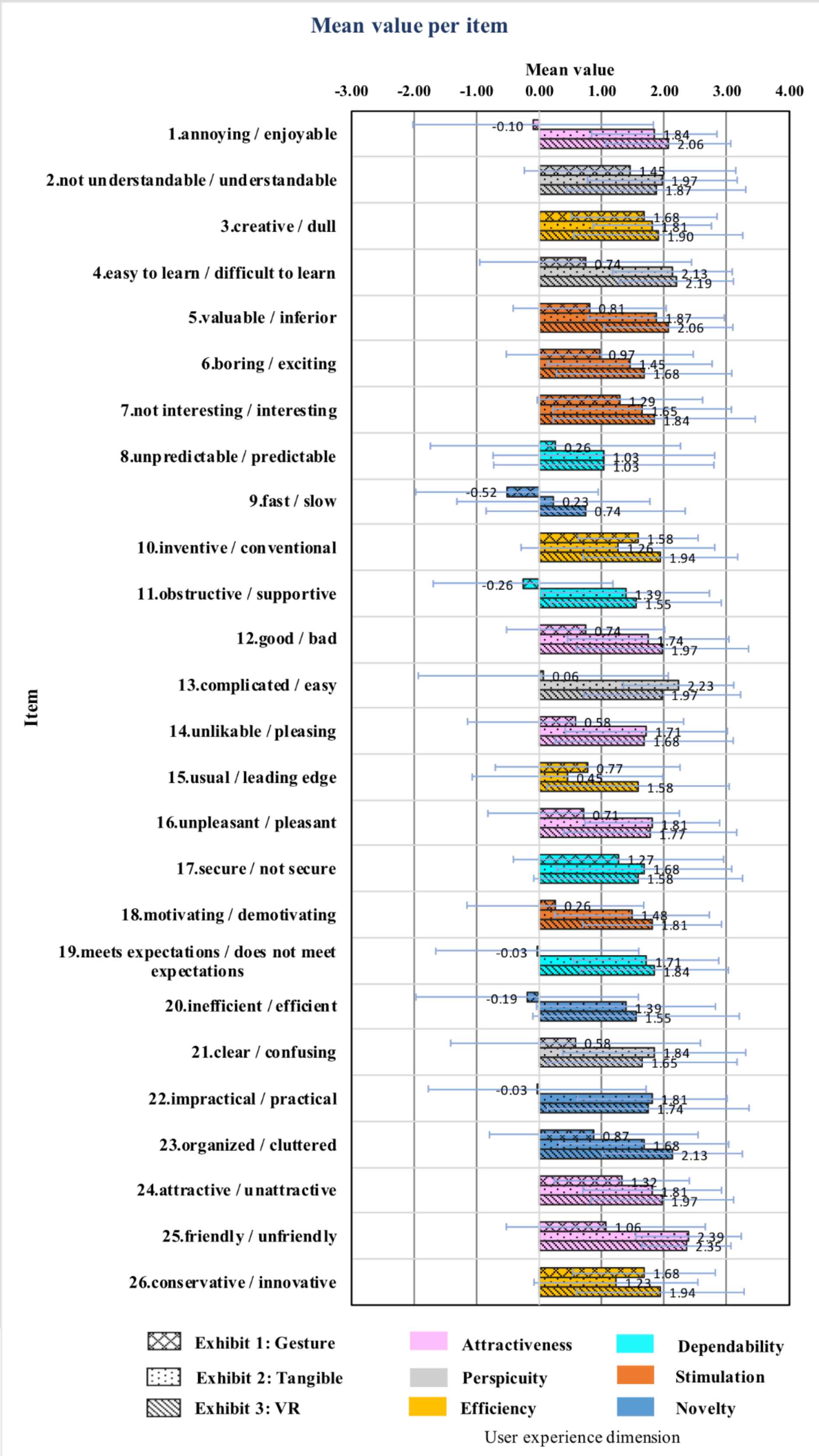


Figure 5.5 The mean value per item of each interface and the error bars with the standard deviation (reprinted from Ref. [163]).

5.4.2 The Overall User Experience by Dimension

Figure 5.5 shows the mean value of the overall user experience by each dimension, including attractiveness, perspicuity, efficiency, dependability, stimulation, and novelty. The statistical results show gesture exhibit receives the lowest score on all dimensions. In comparison, the tangible exhibit gets a higher score than the VR exhibit on attractiveness and perspicuity. The VR exhibit obviously gets a higher score than the tangible exhibit on efficiency, simulation, and novelty. It also gets the same score as tangible on dependability. The Friedman nonparametric test is used to find significance between exhibits and is followed by a post hoc Wilcoxon signed-rank test with the Bonferroni correction ($p < 0.017$, $\alpha = 0.05$) to compare pairs of exhibits. Table 5.2 summarises the statistical result of each dimension.

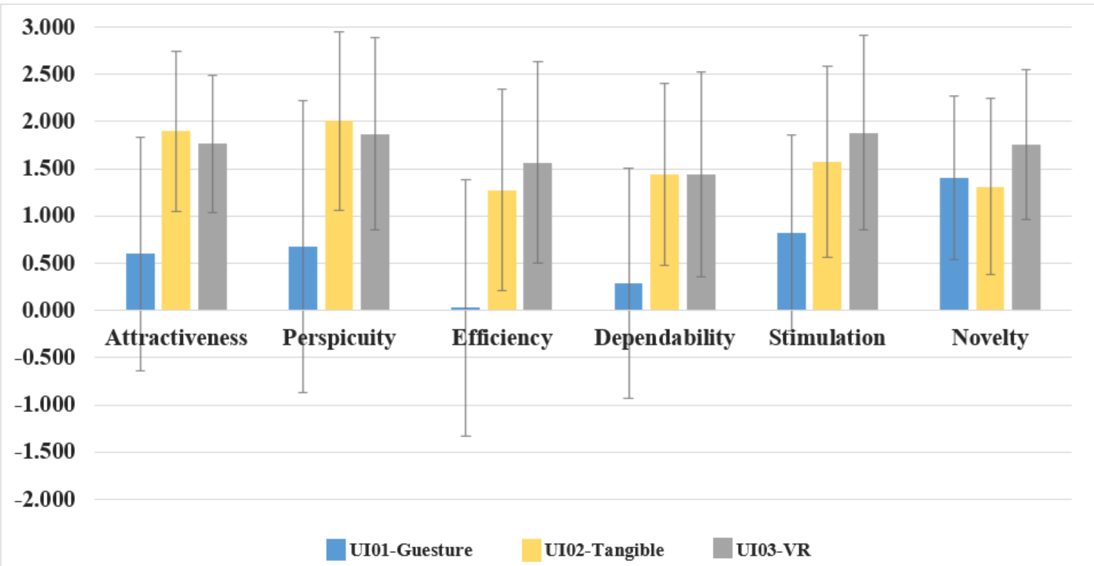


Figure 5.6 Overall mean value per user experience dimension on the UEQ for each interactive exhibit, showing error bars with standard deviation (reprinted from Ref. [163]).

5.4.2.1 Factor 1: Attractiveness

The statistical results show significant differences depending on the type of user interface on attractiveness dimension where $\chi2 = 26.235$, $p = 0.000$. There are differences between the gesture exhibit and the tangible exhibit where $p = 0.000$ ($Z = -3.861$) and between the gesture exhibit and the VR exhibit $p = 0.000$ (Z = -4.018). The tangible shows a higher mean than the two other exhibits, where the mean value is 1.897 (SD = 1.236).

5.4.2.2 Factor 2: Perspicuity

The statistical results show significant differences depending on the type of user interface on the perspicuity dimension where $\chi 2 = 21.876$, $p = 0.000$. There are differences between the gesture exhibit and the tangible exhibit where $p = 0.000$ (Z = -3.804) and between the gesture exhibit and VR exhibit $p = 0.003$ (Z = -3.008). The tangible shows a higher mean than the two other exhibits, where the mean value is 2.008 (SD = 0.944).

5.4.2.3 Factor 3: Efficiency

The statistical results show significant differences depending on the type of user interface on the efficiency dimension where $\chi 2 = 26.248$, $p = 0.000$. There are differences between the gesture exhibit and the tangible exhibit where $p = 0.000$ (Z = -3.996) and between the gesture exhibit and VR exhibit $p = 0.000$ (Z = -4.159). The VR shows a higher mean than the two other exhibits, where the mean value is 1.565 (SD = 1.068).

5.4.2.4 Factor 4: Dependability

The statistical results show significant differences depending on the type of user interface on the dependability dimension where $\chi 2 = 31.113$, $p = 0.000$. There are differences between the gesture exhibit and the tangible exhibit where $p = 0.000$ (Z = -3.570) and between the gesture exhibit and VR exhibit $p = 0.000$ (Z = -4.080). The tangible receives a mean score equal to the VR, where the VR is 1.444 (SD = 0.946), and the tangible is 1.444 (SD = 1.087). The gesture receives a lower mean value than the other exhibits.

5.4.2.5 Factor 5: Stimulation

The statistical results show significant differences depending on the type of user interface on the stimulation dimension where $\chi 2 = 30.154$, $p = 0.000$. There are differences between the gesture exhibit and the tangible exhibit where $p = 0.000$ (Z = -3.996) and between the gesture exhibit and VR exhibit $p = 0.001$ (Z = -3.437). The VR shows a higher mean than the two other exhibits, where the mean value is 1.879 (SD = 1.033).

5.4.2.6 Factor 6: Novelty

The statistical results show no significant difference depending on the type of user interface on novelty dimension where $\chi2 = 0.475$, $p = 0.789$. The VR shows a higher mean than the two other exhibits, where the mean value is 1.755 (SD = 0.796).

Table 5.1 A summary of statistical significance test results of each dimension.

Dimension	Nonparametric test with Friedman (α = 0.05)								Wilcoxon signed-rank tests with a Bonferroni (p <0.017, α = 0.05)		
	χ2	p	Median (IQR)			Mean Rank			Gesture vs. Tangible	Gesture vs. VR	Tangible vs. VR
			Gesture	Tangible	VR	Gesture	Tangible	VR			
Attractiveness	26.235	0.000	0.400 (-0.40 to 1.60)	2.000 (1.40 to 2.60)	1.750 (1.50 to 2.25)	1.27	2.47	2.26	✓ 0.000 (-3.861)	✓ 0.000 (-4.018)	✗ 0.269 (-1.106)
Perspicuity	21.876	0.000	0.500 (-0.50 to 3.00)	2.250 (1.25 to 3.00)	2.000 (1.25 to 2.75)	1.35	2.42	2.23	✓ 0.000 (-3.804)	✓ 0.003 (-3.008)	✗ 0.700 (-0.385)
Efficiency	26.248	0.000	0.000 (-1.00 to 0.75)	1.500 (0.75 to 1.75	1.500 (1.00 to 2.50)	1.26	2.35	2.39	✓ 0.000 (-3.996)	✓ 0.000 (-4.159)	✗ 0.247 (-1.158)
Dependability	31.113	0.000	0.500 (-1.00 to 1.50)	1.500 (1.00 to 2.25)	2.000 (1.50 to 2.75)	1.24	2.19	2.56	✓ 0.000 (-3.570)	✓ 0.000 (-4.080)	✗ 0.890 (-1.701)
Stimulation	30.154	0.000	0.750 (0.00 to 2.50)	1.500 (1.25 to 2.50)	2.000 (1.25 to 2.75)	1.23	2.29	2.48	✓ 0.001 (-3.437)	✓ 0.000 (-4.171)	✗ 0.230 (-1.200)
Novelty	0.475	0.789	1.400 (0.80 to 2.20)	1.400 (0.60 to 1.80)	1.800 (1.20 to 2.20)	1.97	1.94	2.1	✗ 0.983	✗ 0.077	✗ 0.085

✓ significant different

In summary, the type of interface creates an exhibit effect on user experience. The statistics show significant differences between the gesture-based exhibit and tangible-based exhibit and between the gesture-based and VR exhibit. The type of interface also affects attractiveness, perspicuity, efficiency, dependability and stimulation dimensions. On the other hand, it does not show a significant difference between the tangible and VR exhibit. In contrast, the novelty dimension does not show a difference in user experience between the three interactive exhibits. Session 5.5 will discuss this in detail.

5.4.3 Null Hypothesis Significance Testing

5.4.3.1 Hypothesis 1

: VR offer higher user experience quality than using a tangible-based interface, a gestures-based interface, and a VR interface.

The statistical results show a significant difference in user experience between the gesture-based interface and tangible-based interface and a significant difference between the gesture-based interface and VR. It shows differences in five dimensions of user experience, except novelty. Therefore, this hypothesis will be rejected. This means the difference in user interface might influence the quality of user experience differently. Tangible and VR did not show significance in this experiment; however, in some user experience dimensions, the VR received a higher score than tangible, and in some dimensions, the VR received a lower score than tangible. This indicates that each technology has advantages and disadvantages in influencing user experience.

5.4.3.2 Hypothesis 2

: VR has a higher holding power than the gesture-based interface and the tangible-based interface.

The holding power is the exhibit's ability to attract players to pay attention to the exhibit. The statistical results used a nonparametric Wilcoxon signed test ($\alpha = 0.05$) to find significant differences in the time players play with exhibits. There was not a statistically significant difference in playing time which indicates holding the power of the interactive exhibit does not depend on the type of interactive exhibit interface, $\chi2(2) = 3.528$, $p = 0.171$. Median (IQR) playing times, in seconds, for the UI01-Gesture, UI02-Tangible, and UI03-VR interactive exhibit running test were 206.00 (131.00 to 291.00), 177.00 (139.00 to 214.00), and 180.00 (143.00 to 240.00), respectively. Therefore, this hypothesis will be rejected where the holding power is not dependent on an interactive interface. The VR did not show higher holding power than other types of exhibits.

5.4.4 Qualitative Data the Result from the Interview.

A semi-structured interview was conducted after a participant had experienced each design case and again after they had experienced all three design cases. After they had experience with each design, they were asked the same question, and after they had experience with all three designs (tangible, gesture, and VR), they were asked about their overall experience. A summary of the questions used in the semi-structured interview is shown in table 5.3 In addition, video was recorded during the participant interactions with each exhibit.

Table 5.2 The questions in the semi-structured interviews.

Interview Question
1.Which features do you like in this interactive exhibit?
2. Which features do you want to improve this interactive exhibit?
3. What do you learn from this interactive exhibit?
a) About scientific content (what the message that you take from the exhibit)
b) About the feedback from the exhibit (sound, colour, animation)
4. Other recommendation?
5. Overall experience?

All interview records are automatically transcribed into text files using the Otter.ai program. Then, all the transcript files are corrected for each sentence by the researcher. After that, all edited transcript files are analysed using NVivo software for coding and themes analysis, as suggested by Bopp et al. [23], Gowler and Iacovides [74], Braun and Clarke [24], Terry and Hayfield [209]. The final themes are shown in figure 5.11. Illustrative quotes are labelled with participant number and when they mentioned, after played gesture, tangible, VR, or overall experience. For example (U001, gesture) means the quote is from participant ID U001 and interview after played gesture exhibit. (U002, overall) means the quote is from participant ID U002 and interview after playing all three exhibits.

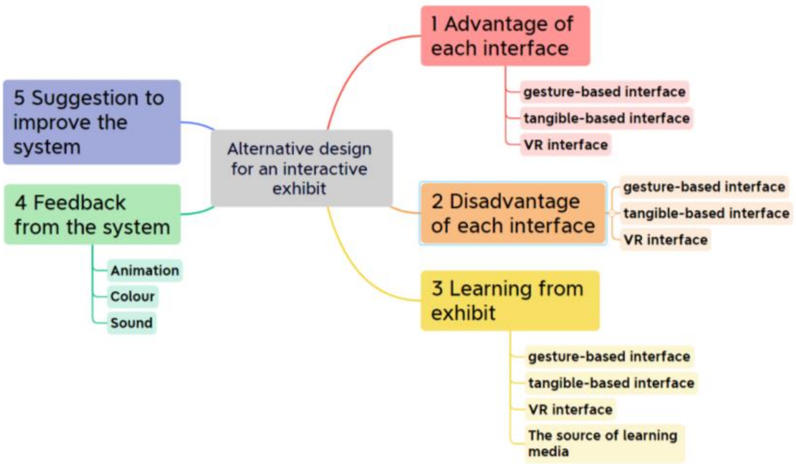


Figure 5.7 The final thematic map representing the five key aspect influencing user experience when use different technology.

5.4.4.1 Theme 1: Advantage of Each Interface

This theme will mention the good points or dominant features of each interface.

Exhibit 1 gesture-based interface: the gesture was a nice and new experience for participants (U001, gesture). Using gesture technology is new for participants, and they learned how to use it and how it works (U022, overall). The sensor was interesting to use (U016, gesture) (U004, gesture). Participants liked to use their hand to control the system freely (U014, gesture) (U015, gesture) (U021, gesture). It was attractive to play with and interesting how to use the hand to control the object properly (U008, gesture), and it was a surprise (U022, gesture). They enjoyed seeing their virtual hand movement on the screen. It was fun (U011, gesture). They loved the virtual hand design, which does not touch but can control the object and makes them feel free (U012, gesture). They feel a sense of their hand moving on the screen to pick up an object (U018, gesture). Seeing their virtual hand moving on screen is very enjoyable (U028, gesture), and it is a very impressive feature (U026, gesture).

The gesture design is very high innovation and technology (U017, gesture) (U008, gesture). It is a new idea and offers more motivation to read than others (U013, overall). They like the design of the presentation of the gesture exhibit (U031, gesture). They like the system showing everything on one screen. It engages players, causes them to focus more on the media and makes them want to explore the media more (U002, gesture) (U023, gesture) (U030, gesture). They were able to see animation and text on screen clearer than in VR (U025, gesture).

Exhibit 2 tangible-based interface: the good aspect of tangible was able to touch objects (U002, overall) (U008, tangible) (U009, tangible) (U010, tangible). Touching a physical object gave them joy (U014, tangible). To touch a 3D model feels better than seeing a visual graphic (U017, tangible). Being able to touch the object while seeing the 3D model is quite interesting (U016, tangible). Players feel close to nature when they touch and sense the object's texture (U017, overall). It makes them feel like they touch real things-frog and mushrooms (U018, tangible). Touching the object makes them feel they are actively playing the exhibit by themselves "…I think it gives me the sensation that I'm creating that information and not just being fed to me" (U012, tangible). They feel engagement to play (U026, tangible) (U022, tangible) and enjoy picking up the physical model (U028, tangible) (U030, tangible) (U031, tangible).

Interacting with the exhibit by hand, like picking up and dropping an object, is easy to understand (U025, tangible) (U026, tangible). It is quite easy (U004, tangible) (U006, tangible) and intuitive (U011, tangible). One participant felt the simplicity of this interface

(U003, tangible). Players felt comfortable playing with this interface (U001, tangible) (U010, tangible). Players liked the design of this exhibit. They enjoyed playing with the exhibit like a toy that felt less dangerous (U012, tangible). It is quite playful (U011, tangible). They like the tangible exhibit design that combines physical objects and technology, allowing people to touch the object and use digital technology to display information (U015, tangible) (U029, tangible). It is really good, more so than using only technology (U028, tangible). Another good aspect of tangible is that many people can participate in this exhibit together (U020, tangible).

Exhibit 3 VR interface: VR is a useful technology to offer an immersive experience (U009, VR) and is more innovative compared to others (U023, VR). It is a very interesting experience (U003, VR) (U023, VR). It induces players to pay attention to media (U026, VR). VR offers the feeling of being in the forest to players (U022, VR) (U020, VR) (U023, VR). VR brings them to another world (U013, VR) (U016, VR). Players feel involved with the whole virtual environment (U001, VR), especially wearing a headphone that offers a more immersive sound experience (U014, overall) (U026, VR) (U030, VR). Players enjoy the sound effect (U005, VR). The surround sound was nice and pleasant (U029, VR) and calm and peaceful (U014, VR).

Many participants mentioned that VR is very intuitive to play (U011, VR) (U028). It is easy to grab an object (U018, VR) (U023, VR) (U027, VR). It was very responsive (U006, VR), and it made a more enjoyable and fun experience (U019, VR) (U031, VR) that gave the player a chance to play more (U008, VR). VR is useful for teaching complicated content (U023, VR).

5.4.4.2 Theme 2: Disadvantage of Each Interface

This theme will mention the weak points of each interactive exhibit. And the issues found in this study also will be mentioned. Each interface found issues both based on technology and the user itself.

Exhibit 1 gesture-based interface: participants found the gesture-based is difficult to use for many reasons. For instance, they are unfamiliar with using the sensor, it made it difficult to grab objects (U010, gesture) (U023, gesture), and they felt it was complicated to use (U015, gesture) (U028, gesture). The difficulty in controlling the objects in the VE comes from the fact the sensor did not detect the player's hand (U009, gesture) (U011, gesture) (U013, gesture). The virtual hand did not follow the player's hand (U012, gesture). The object in the VE was very small (U022, gesture). The layout that paced the objects was difficult to reach, especially when the objects were obstructed by another object (U030, gesture) (U010, gesture), and their position was too close to another model. The response of the system is very slow to hand movement (U021, gesture) (U016, gesture) (U026, gesture).

The difficulty in controlling the object made the players feel annoyed (U001, gesture) (U003, gesture) (U017, gesture) (U028, gesture). It makes them feel frustrated (U002, gesture) (U014, gesture) (U018, gesture), felt disappointed (U029, gesture), and felt uncomfortable (U016, gesture) using the gesture exhibit. They felt confused controlling the direction (U009, gesture) (U031, gesture) (U019, gesture) (U024, gesture), and felt pain in their hand, "My hand hurt when I tried to move them" (U001, gesture).

Exhibit 2 tangible-based interface: tangible interface found some weaknesses in the delay of the sensor to activate display animation on the screen (U027, gesture). The delay of displaying animation when putting a new model did not immediately show new animation but still showed previous animation (U014, gesture) (U017, gesture) (U020, gesture) (U031, gesture). Sometimes the sensor did not work (U025, gesture). Players felt it was less magical to play with the tangible exhibit "…able to touch it and pick it up, but it felt less magical." (U012, gesture), and the model might often be lost when displayed in museums (U029, gesture). The design of the tangible display shows the feedback in two places: on the interactive play box and on the screen. A player reported that she did not look at the feedback on the screen and only looked at the result from the box (U021, gesture).

Exhibit 3 VR: players felt uncomfortable wearing the VR headset (U010, VR). The VR headset is quite heavy (U009, gesture) (U023, gesture). It makes players feel dizzy when they wear it for a very long time (U017, gesture). The text information in the VR is not clear for players to read (U003, VR) (U017, VR) (U019, VR) (U025, VR), especially for people who have poor eyesight (U009, VR). The VR headset is for personal use (U012, VR), only one person can see at a time, and other people cannot see and play with another family like the tangible exhibit (U020, VR).

5.4.4.3 Theme 3 Learning from Exhibit

This theme will mention how players learn from each exhibit and what media source helps them learn. The issues affecting players to gain knowledge from the exhibits in this experiment are also mentioned.

Participants could interpret the meaning from the exhibit's feedback in which they could distinguish that some frogs and mushrooms are normal that can be eaten and can be touched. Some of them are poisonous (U015, gesture) (U023, gesture) (U028, gesture) (U030, gesture), cannot be eaten and induce symptoms when eating them (U022, tangible). The animation of the girl shows the participants and lets them know how the mushroom affects the human body (U006, tangible) (U021, gesture) (U024, gesture). Once participants could interpret the meaning of the feedback, it made them aware that mushrooms and frogs enable to harm humans; they mentioned they should be careful about mushrooms (U012, VR) (U014, VR) (U022, VR), and “don't touch, eat or smell a poisonous dart frog” (U027, VR). Participants learned the scientific name of mushrooms or frogs from reading text displayed on the animation (U016, gesture) (U020, gesture) (U025, gesture) (U026, gesture) (U013, tangible) (U005, VR) (U020, VR) (U013, VR). Participants could distinguish the characteristic and appearance of mushrooms and frogs from the 3D model, both the tangible model (U007, tangible) and virtual model (U021, VR) (U007, VR).

The feature of each exhibit was found to affect learning from the exhibit. A participant stated that VR helps the player pay more attention to the animation, which helps the player understand the exhibit's content more (U004, VR). A player mentioned that tangible was better to control the input, more than the gesture, which helps the player to concentrate on content more (U026, tangible). In contrast, the study found that some participants did not get many messages from the gesture exhibit for many reasons. For example, they pay attention to using a sensor that is a new technology for them (U018, gesture) (U012, gesture) and try to familiarise themself with using the sensor (U010, gesture). Another reason for the system's difficulty interacting with the model is that they try to pick up the object. This makes them lose concentration on the content (U014, gesture) (U029, gesture). When they cannot pick up the model, the player will lose a chance to reach the exhibit's content (U011, gesture).

The source of learning media found that no modality is significantly better at offering knowledge to the player. It found a variety of patterns by which the player receives the content. The gesture and tangible often found that the participant learned from animation and colour light up, while some learned from the animation and the reaction of the girl tell the meaning (U007, VR) (U010, tangible) (U015, tangible), "…that little girl got sick, or she died… cannot eat the frog" (U031, gesture). Some participants learn from colour (red, green, blue) first and then learn from animation (U003, VR) (U029, VR) (U022, tangible). At the same time, some participants look at animation first and then look at colour (U029, tangible) (U030, tangible) (U014, VR). A participant mentioned tangible "…I was looking more at the screen this time, the reactions, the animations…" (U029, tangible). One player found reading text in VR difficult because the text was not clear. They mentioned they learn from sound (U029, VR) and learn from colour (U021, VR).

5.4.4.4 Theme 4: Feedback from the System

This theme will mention the feedback of the system in general. The feedback includes animation, sound, and colour. In general, participants stated that the feedback from the system is universal "Those are universal signifiers of what's good and bad…" (U011, tangible), and they like the combination of all feedback (U031, tangible). The multimodality feedback of the system displays at the same time, so the player cannot perceive all of them at the same time (U004, tangible) (U007, tangible), but it is good that it provided them with a choice to get information (U004, VR). The detail of the feedback will be described below.

Animation: the animation is quite attractive and interesting to look at (U018, VR). The feedback from the system use signs to represent the meaning so that the players can understand the message by implying animation, even if they do not understand the language (U023, tangible). A participant said, "I really liked the funny things like I eat more protein. It's something that you can eat." (U030, tangible). Participants like the idea of the communication design of animation. They felt good and impressed with the animation (U016, VR) (U003, VR) (U008, VR) (U029, VR).

However, some players confused the meaning of the animation when the light turns to a yellow warning (U004, VR). Animation is quite quick (U011, tangible), and the action animation of eating and smelling is quite similar, so it is difficult to distinguish (U007, tangible). Text explanation in animation needs to be bigger (U004, VR).

Colour: A participant stated that colour feedback is simply designed “...the colours are very, very palatable. They are relatively simplistic colours, and just presumably, painted, we have the likeness of what was shown, that was very good...” (U011, tangible). They like the idea of changing the colour of LED depending on good or bad (U030, tangible). However, some participants mentioned that they were confused the meaning of yellow colour (U026, tangible) (U009, gesture) “it being green, presumably edible, red, presumably inedible, it was yellow. And I didn't know what that meant.” (U011, tangible). Another weak point is that the colour feedback was shown for a short time (U005, tangible).

Sound: almost all participants mentioned that they like the sound background that brings them to seem to be in nature (U008, gesture) (U009, gesture) (U030, gesture), saying it was really relaxing (U006, gesture) (U011, tangible). The sound feedback is very clear in the VR (U002, VR) (U007, VR). The weak points of sound feedback are that it is not clear in the meaning (U005, VR). The sound is not heard differently between green colour and red colour (U004, tangible). The round beep sound sometimes annoyed the players (U004, VR) (U003, tangible).

5.4.4.5 Theme 5: Suggestion to Improve the System

This will mention the suggestion to improve the system from the participants’ recommendations. Participants suggested adding more information about each mushroom and frog (U001, tangible) (U008, tangible) (U017, tangible) (U015, VR) (U019, VR) (U031, VR), such as the size of the frog and colour (U022, VR). Adding the voice-over text information to help players who were unable to read the text to receive the information (U003, VR) (U026, gesture), put a description of the meaning of the feedback to avoid players misunderstanding (U015, tangible) (U018, tangible) (U029, tangible). Finally, they suggested the narrative of the exhibit to a game style that makes it more fun and help players to remember content (U003, tangible).

The suggestion for VR is to create a virtual forest environment (U003, VR) (U016, VR). A participant said using VR is tiring. It should be used for experience rather than information, “I expected more to be about just feeling things or getting the impression about things” (U026, VR), for example, creating a survival trail in the forest (U006, VR). The suggestion for the tangible is that improving the quality of the model should use the realistic character of the model (U004, tangible) (U011, tangible) (U016, tangible) (U026, tangible).

A suggestion for the gesture, to help solve the difficulty of picking up the object, is to create more space between the model (U014, gesture), adding the snap zone (U027, gesture), creating a drop area bigger (U028, gesture), and to have a function that brings the model automatically back to the home position (U007, gesture) (U010, gesture). A participant mentioned the cause of the difficulty in using the gesture is that "… don't use gestures for, I think. Unless the technology gets a little bit more reliable, it sounds ridiculous, but it was even sort of tiring…, having to hold your hand like that… I'd recommend not pursuing this one" (U029, gesture).

5.5 Discussion

This study investigated how user experience differs when using different techniques and what factors affect user experience. The study explored three different exhibit interfaces: gesture-based interface, tangible-based interface, and VR. All three exhibit participants reported that it delivered an immersive experience to them, like being in the forest with a sound background. The statistical results show a difference in user experience between the gesture-based and tangible-based exhibits and between the gesture and the VR. There were significant differences in five of six user experience dimensions, including attractiveness, perspicuity, efficiency, dependability, and simulation. In contrast, the tangible-based interface and VR did not show significant differences in all user experience dimensions. This session will discuss and explain the reason for the results.

5.5.1 The Balance between Novelty and Unfamiliar.

All three exhibits kept the same design features of sound, animation, colour, narrative style and scientific content. Almost all participants gave positive feedback on the communication style of the animation, stating it was fun and friendly. The sound background offers an immersive experience to participants, like being in the forest. It indicates that all three exhibits deliver the same feature to users.

The novelty in the UEQ did significantly differ across the three exhibits, even on the classic interface like tangible. The result found that participants mentioned that each exhibit was a new experience for them to play. They are quite interested in the new input technique. For the tangible, they like the combination of the physical object and digital display. For the VR, they like using the controller to pick up the object and the 3D virtual environment, and the gesture they were excited to see their virtual hand on the screen and play with their hand without touching the object. Every interface has its own dominant feature. However, the results found participants had difficulty interacting with the gesture exhibit that they not previously use. This factor makes the user experience different. Museum exhibits should consider the trade-offs between unfamiliar and familiar input techniques. When users are unfamiliar with its use, the technology will affect user experience.

5.5.2 Interaction Challenges

The task design for an exhibit but using a different interface might affect user experience. A simple interaction of picking up and dropping an object when the design on a tangible-based interface and VR, the participants stated the task is easy and intuitive for them to play. In contrast, using the gesture-based they found it very difficult to play. In particular, it was difficult for them to reach the object. As a consequence, the player felt annoyed and stopped interacting with the system.

The statistical results show that the tangible-based interface receives a significantly lower score than tangible-based and VR on perspicuity, efficiency and dependability. Similar to what was found in the study of Georgiou et al. [65], regarding the technology, difficulty in controlling the game during learning and interacting with the system affects the learner's experience. This issue is explained by referring to Task-Technology-Fit (TTF), the relationship between the characteristic of a task created for a system and the ability of the technology. Each technology has unique functionality, making it able to perform some tasks [205]. A well-matched task or activity with the functionality of the technology will produce a good performance to help users achieve the goal of the task. For example, in the study of Potter et al. [167] the Leap motion sensor allows the player to interact with the system using drag and drop object technique but with poor performance due to issues using the sensor.

5.5.3 Learning Outcomes

All three exhibits delivered the same scientific content, but the result shows tangible-based exhibit and VR exhibit have the same efficiency in delivering knowledge to the player. After participants experienced the exhibits, they reported that they gained knowledge from the exhibit. Example knowledge includes: the scientific name of mushrooms and frogs, the characteristic of mushrooms and frogs, the ability to classify edible and inedible mushrooms and knowing to be careful when touching frogs. In contrast, in the gesture-based exhibit, many participants stated that they had experienced that they did not learn from the exhibit. The reason that they did not get knowledge from the exhibit is they paid more attention to how to interact with the system, trying to familiarizing themselves with the technology, leading to difficulty interacting with the system.

The aim of the interactive exhibits in STEM museums is to deliver learning content to visitors, so one should consider some factors of exhibit design that affect visitors' learning. The results from this study indicated that pragmatic quality: efficiency, perspicuity, and dependability, affect learning outcomes. The difficulty of using a system depends on the user, especially whether the system is easy or complicated or if the system is easy or difficult to learn. The gesture-based got a lower score than tangible and VR. These factors prevent learners from reaching the learning content of the interactive exhibit and decrease the chance of learning all the content from the learning media.

5.5.4 System Feedback

The system used multimodal feedback that gives information to the player via three combination modes: visual animation, visual colour, and audio. The result shows that players receive the learning message from all modalities of feedback. It supports the various learning preference of players. However, some participant mentioned that showing all three feedbacks at the same time meant they could not pay attention to all of them. Some players look at the animation first and then the colour, while some players look at the colour first and then the animation. This is due to the layout design of tangible, where the colour feedback and animation were not shown in the same place. Also, the player who plays the VR and has eyesight problem cannot read the text in the animation clearly and will get the message from the colour light up and sound instead of animation as the first source.

However, using multimodalities is better than one. Using auditory feedback might not be efficient in a STEM museum's environment, when sometime can be loud and crowded visitors. Therefore, in this situation, another modality of feedback can offer the feedback to the player instead. Vitense et al. [219] found that bimodal feedback enhances the learning experience and offers an opportunity for the player to interact with the system continuously when the other modality is unable to perform. The most beneficial feedback occurs when a response to the player at an appropriate time is related to the exhibit and has meaning [29]. It corresponds with the feedback of this study to use the multi-source of feedback. For example, the player looks at the animation and explores how the biotoxin effects human organs. The sound and colour help the player quickly indicate that frogs or mushrooms are dangerous.

Another point to consider about the system feedback is the meaning of the feedback. The feedback of the system used an analogy technique to present information that lets players imply the meaning from signs in the feedback, such as red means dangerous or bad, and green means safe or good. It is a universal use to represent the meaning. Some participants reported that they were confused with the animation when the system showed yellow feedback. The participant stated that they could interpret things that show opposite meaning (dangerous/safe), but they need to figure out the meaning of the feedback when shown yellow (the system wants to warn the player it can be dangerous). It should be considered that the analogy technique for design feedback might cause the player to be confused about the meaning or misunderstand the feedback. A suggestion that the participant mentioned was that adding the description along with the feedback will enhance the feedback and make clearer the meaning.

5.5.5 Six Aspects for Choosing Interface

The results of this study suggest the following six aspects should be considered when selecting a technology between VR and an alternative, and when design interaction for VR.

1) Novelty: novelty is one feature of interactive exhibits to attract visitors. The result of this study indicated that novelty does not only mean new technology but that it could simply be new for the people using the exhibit. The interface that they are not used to using in everyday life will feel new for them. In this study, the players also mention that the simple interface, like the tangible-based exhibit, is a new experience for them, as they mentioned for the VR. Holding time that indicated how long the player paid attention to the exhibit between the three types of interfaces. No significant difference was found, suggesting that all three interface types can hold participant interest at the same level.

2) User-friendliness: tangible and VR technologies were found to offer the same quality of user experience, both better than gesture-based exhibits in this study. The participant reported that it is easy to interact with the tangible-based exhibit and VR. In contrast, they stated that it is difficult to interact with the gesture-based exhibit. The difficulty of interacting with the system distracted the player from paying attention to the content of the exhibit. Based on the result of this study, one should consider the ease of interacting with the system when choosing a technology.

3) Precision of the input device: one of the biggest effect on quality of user experience is the poor precision of the input system. The imprecise input will make the system difficult to interact with, and if case users feel annoyed with using it, then they will stop playing the exhibit. The problem of the input system can be due to the input device or the skill of the software developer.

4) Task and device design: the fact that each technology has its own functionality, so design interaction for an exhibit should consider how well the device is suited for performing the task design for the exhibit. The action design should be related to the characters of the input device. If not, this will affect how people interact with the system. Results found the Leap motion device was inappropriate for use with the action and caused players to have difficulty using the exhibit. Also, it was found that one button and one action design for the controller of the VR exhibit makes players quickly understand and makes it easier to interact with the system.

5) Multi-modality of feedback: designing the feedback with a multiple forms of feedback is better than using only one mode of feedback. The three feedback modalities: visual animation, visual colour and audio, serve as a backup of each other when the player is unable to perceive information from another mode. However, the meaning of the feedback should be related to the exhibit content.

6) Quality of text in VR: one issue with using the VR found in this experiment is the quality of text in the VR. Participants, especially those with poor eyesight, reported difficulty in reading text information in the VR, so designing content to deliver information to visitors via text should consider the quality of the text. A suggestion was to have voice-over text for information in the VR. This would help players with this issuer to still obtain the information.

5.6 Conclusion

This study intends to investigate factors that affect the user experience when using different types of technology to create an exhibit. The study examines three different types of interfaces: gesture-based interface, tangible-based interface, and VR by developing three interactive exhibits based on each interface that deliver the same scientific content and narrative style. The three exhibits offer knowledge to visitors about biotoxin in nature. The experiment had two hypothesises: H1- *VR offer higher user experience quality than using a tangible-based interface, a gestures-based interface*; and H2- *VR has a higher holding power than a gesture- and tangible-based interfaces*.

The study uses a mixed method approach, quantitative and qualitative. The quantitative measure of user experience is performed using the UEQ questionnaire and holding power. The UEQ comprises six dimensions of user experience: attractiveness, perspicuity, efficiency, dependability, stimulation, and novelty, each scored on a 7-point Likert scale. Holding power was measured by the total time that the player played with each interactive exhibit. The qualitative study used a semi-structured interview after the participant had experienced each exhibit as well as a video record. All the interviews are converted to a transcript and thematic analysis was used to analyse the data. This experiment was used within the subject study. Thirty-one participants joined this experiment.

The statistical results applied the Friedman non-parametric test followed by a Post hoc analysis to find significant differences between pairs of design by Wilcoxon signed-rank tests with Bonferroni correction ($\alpha = 0.05$, $p < 0.017$). The result shows that there are significant differences between the gesture-based interface and tangible based-interface and between the gesture-based interface and VR. It did not show a significant difference between a tangible-based interface and VR. The difference found in five user experience dimensions in UEQ includes attractiveness, perspicuity, efficiency, dependability, and stimulation. The novelty dimension did not show a significant difference. The statistical result of holding power did not show a significant difference across the three exhibits. This indicated that the different types of interface did not affect how players paid attention to the exhibit, or it meant the three types of interface attracted visitor interest at the same level.

The analysis of the results suggests six aspects to consider when deciding to choose an alternative technology to create a new interactive exhibit. The six aspects include novelty, user friendliness, precision of the input device, task and device design, multi-modality of feedback, and quality of text in VR. These suggestions can be used as a guideline for choosing an appropriate technology to create an interactive exhibit for museum learning, especially when comparing VR with another choice of available technology.

Chapter 6 Social Interaction Design in VR for Museum Study

6.1 Introduction

Social Context is essential for informal learning in museums. It is a strategy for designing an exhibit to engage visitors [54] [56] [20] [53]. Indeed, a conversation between members in a group is significant for social interaction to share their knowledge and exchange experiences [64]. However, evidence found from the museum observation in Chapter 4 suggests that VR lacks a mechanism to support social interaction between visitors, especially for families visiting the museum, where a parent wants to explain scientific content to their children or ask questions to encourage their child with the exhibit. This study aims to find a solution providing social interaction for visitors while playing VR exhibits, thereby enhancing the museum experience.

This study addresses research aim four by investigating the social impact of using a VR interactive interface in the museum context. It simulated three design cases for connecting players using a VR exhibit: single player (D1), symmetric multiplayer connection (D2), and asymmetric multiplayer connection (D3). This experiment used a simple feature design for an avatar to represent a player in virtual environment (VE). This study examines the connection between player design, avatar features and social activity of each design case with the potential to support visitors' communication, discussion, knowledge exchange, shared experience, and general interaction with other visitors. The results will be used as a guideline for designing the Social Interaction component in the framework.

Section 6.2 outlines the goals of this study. Section 6.3 explains the study's design, including system design, content and narrative story, system implementation, participants, measurement, and procedure. Section 6.4 reports the results found from this study, both quantitative and qualitative. Section 6.5 discusses the interpretation of what this experiment found, along with a suggestion for designing a VR exhibit. And the last part, section 6.6, will summarise the findings of this study.

6.2 Study goals

This study purpose to explores a solution for provide a social interaction mechanism when visitors play with a VR exhibit, by considering the factors that influence social activity and communication between visitors.

Research question

The research questions for this experiment are **RQ1**: what kind of activity will create social interaction in VR? and **RQ2**: what kind of social mechanics and design features of VR is best suited to deliver a science experience via VR?

Hypotheses

There are three hypotheses that this experiment intends to investigate.

Hypothesis 1: There is no difference in the feeling of presence between single-player, symmetric multiplayer connection, and asymmetric multiplayer connection.

Hypothesis 2: There is no difference in the efficiency of social interaction for communication between a symmetric multiplayer and an asymmetric multiplayer connection.

Hypothesis 3: There is no difference in learning experience between the exhibits which use multiplayer designs (symmetric and asymmetric) and those that use single player design with respect to exchanging knowledge, engaging players to play with the exhibit and decreasing loneliness.

Variables

The variables for this study are:

Independent variables: the three design cases of connecting players for VR exhibit are D1, D2, and D3.

Dependent variables: a sense of presence, copresence, social presence, engagement, and knowledge exchange.

Control variables: the topic of the content, the narrative content, and activities of the exhibit.

6.3 Study Design

6.3.1 System Design

This experiment uses three design cases to simulate possible mode of players' social interaction. The three design cases are shown in figure 6.1. The detail of each design is described as follows:

1. **Design 1 (D1),** a single player design case. This design simulates a situation where an exhibit allows only one player to experience being inside the virtual environment (VE) while other visitors stand outside the VE, either accessing via head mounted display (HMD) VR or PC.

2. **Design 2 (D2)** is a symmetric multiplayer connection design case. This design simulates a situation in which an exhibit allows two players to experience being inside the VE together, and both players use VR to access the VE.

3. **Design 3 (D3),** an asymmetric multiplayer connection design case. This design simulates a situation in which an exhibit allows two players to experience being inside the VE together, where the players use different devices to access the VE: one player uses VR and another uses a PC. D3 is an alternative method to connect players to an exhibit together while enhancing the visibility of the VR exhibit content, making it visible to other visitors and allowing them to experience the VR exhibit simultaneously.

All three designs feature an avatar that allows players to interact with the VE and their partner in the game. The player can communicate with their partner in the game by voice. The avatar's hands move according to the player's hand movement. The design provides a mechanism that allows a player to point at an object that they want to discuss with other people by using a laser pointer feature. The appearance of the avatar design is shown in Figure 6.2.

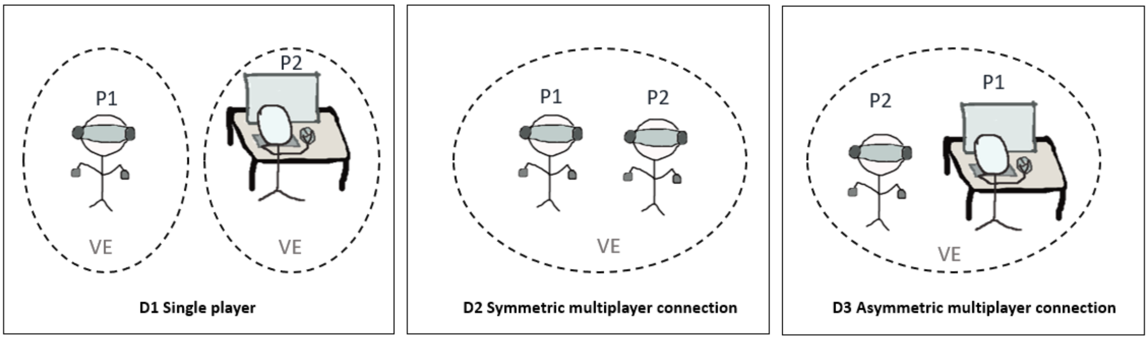


Figure 6.1 The illustration of three design cases for connecting players: D1 single player, D2 symmetric multiplayer connection VR and VR play together, and D3 asymmetric multiplayer connection VR and PC play together.

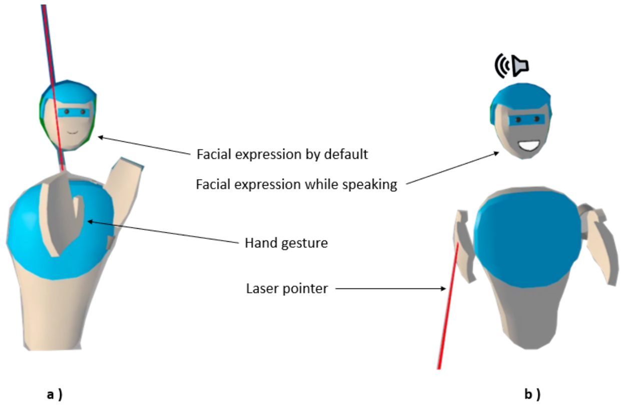


Figure 6.2 The Avatar is designed to represent a player in a virtual environment a) The avatar's facial expression when idle, and b) the avatar's facial expression while speaking.

6.3.2 Content and narrative story

The exhibit educates how the Newcomen steam engine works and its purpose to players. Choosing this topic enables researchers to explore the idea of applying VR to display huge working old machines which are unable to do this in physical museums. And the big model induces players to move to explore it, so this provides the researcher to observe the movement of players who experience the exhibit. The narrative style uses a mix between storytelling and game-based learning, which comprises four game styles: exploration, quiz, explanation, and the completion of a mission. The four game styles are chosen based on those often found in museums exhibits from the result of Chapter 4 Museum observation study. And the researcher expected these games to induce players to have conversations.

1) **Exploration**: a game style design for players to explore parts of the steam engine. The player can pass this game by exploring every component of the machine.

2) **Quiz**: a game style design for players to answer a set of questions about steam engines. Questions provide descriptions and ask players to find the correct part of the machine. Each question tells its function and connects one part with another part of the machine to help players determine the correct answer.

3) **Explanation**: this style tells a process of how the steam engine works. It shows animation with a voice-over explaining each step. Players listen and can walk around the machine.

4) **Complete a mission**: a game style challenges players to complete a task within a time limit. It simulates a situation where players must work and solve the problem together. This exhibit creates flooding in a mine situation for players to solve. Players must operate the machine, open or close the machine's valves to make the beam move and pump water out of the mine to prevent flooding.

Each design case uses the same games, but the question in the quiz game is different to prevent players from knowing the correct answer and reduce conversation between players. The game flow uses linear design, where the next game appears after the current game is finished. In this exhibit players play the sequence of the games as follow: an exploration game, quiz, explanation and complete a mission. The four game styles of this study are shown in Figure 6.3.

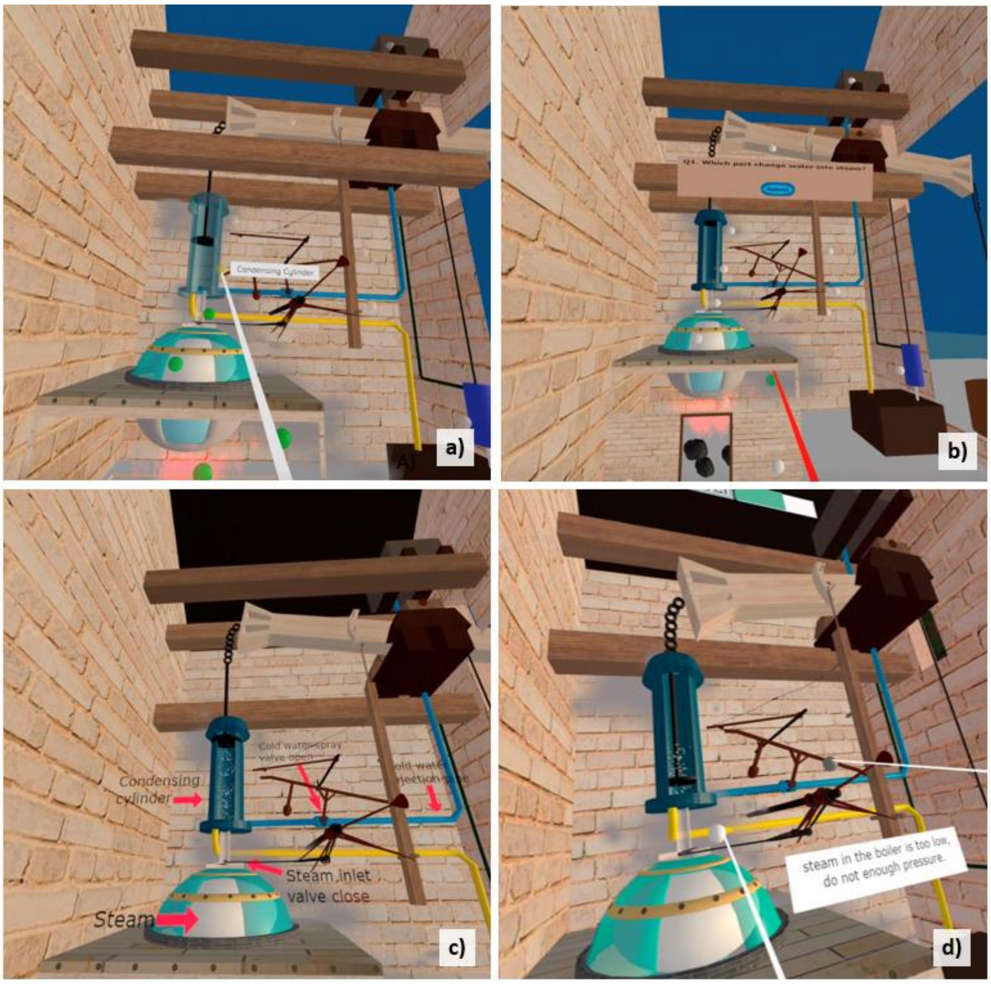


Figure 6.3 The example of the four game styles, with scenes from a) exploration b) quiz c) explanation, and d) complete a mission.

6.3.3 System Implementation

Unity is the main software used to develop the games for both the VR and the PC, while Blender is the primary software used to create 3D models for the game. Each piece of the 3D model is imported into Unity and used to create an animation. Labels and text information in the game are created using the software package Gimp and imported into Unity as a piece of the 2D sprite.

A free package version of Photon Unity Networking (PUN) is used to handle multiplayer and cross-platform in-game networking. The game uses a cloud service platform from PUN without installing its own server, and both PC and VR headset use a Wi-Fi connection. The Photon voice service is used to handle voice chat in the game.

The sound setting on Unity applies 3D sound effects, in which the volume depends on distance from the sound source. The minimum distance is set equal to 1, and the maximum length equal to 500, with the intent of forcing players to stand close to their partner able to use their voice to communicate.

For the interaction design on the PC, a player uses the mouse for pointing to an object and to pan the view in the VE. Players press the scroll wheel and move for pan left-right and to look up-down. Players use arrows on the keyboard to move left-right and forward-backward. For the interaction design in VR, players use both controllers, one in the left and one in the right hand to interact in VE. Player use the thumbsticks for movement in VE and use the Grip button to grab or select an object.

6.3.4 Participants

This experiment uses a within-group study by recruiting, via email invitation, 20 pairs who know each other beforehand. The aim was to use data from ten participants in each of the VR role and PC role for each design case to permit a comparison the quality of user experience between VR and PC. However, in practice, the experiment conduct under the Covid-19 pandemic and only 12 pairs were able to participate in the experiment.

6.3.4.1 Participant Demographics

Data were collected from 12 pairs of participants (24 people), 9 male and 15 female. 21 reported that they rarely visit museums, and 2 people never visit museums. 12 people never played online exhibits and 11 reported that they rarely play online exhibits. 11 had never played with VR before and the remaining reported they rarely play VR. Almost all participants, 23, reported using a PC daily. For each role in D1 and D3, 12 people play the exhibit by PC (R1), and 12 people play the exhibit by VR (R2). Figure 6.4 summarises participants’ background information.

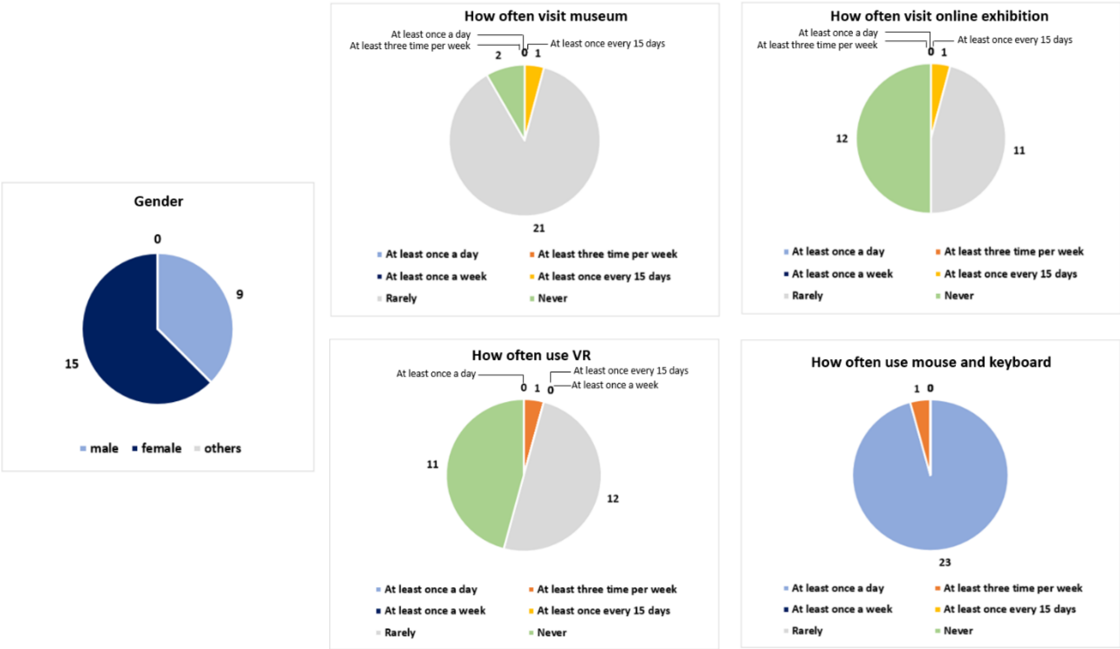


Figure 6.4 Participants' background information.

6.3.5 Measurement

The experiment uses quantitative and qualitative data to test the hypotheses and answer the research questions. A questionnaire is created by the researcher which considers factors to find answer of the hypothesis. To identify whether multiplayer decrease immersive experience sense of presence from single player or not, and the asymmetric multiplayer decrease sense of presence from symmetric multiplayer or not (**Hypothesis** 1), So the Presence is measured. To examine the efficiency to provide social interaction of symmetric multiplayer and asymmetric multiplayer (**Hypothesis** 2), so Co-presence and Social presence are measured. Co-presence measure player feel in the exhibit together and Social presence measure the quality of the system offer player able to communicate and has social interaction in the VE. To investigate asymmetric multiplayer support player to learn from the exhibit, it able player to exchange knowledge and engage them to play or not (**Hypothesis** 3), so Engagement and Knowledge exchange are measured. The detail of each factor describe as follows.

1) Presence refers to sense of being there in the simulation environment, and the level of user experience in response to the simulation world, people who highly have sense of presence will feel more VE is visited place rather than an image seen [198]. This factor aims to examine sense of presence across the three design cases. The items derived from suggestion 4 core components to create illusions of Presence that proposed by Jerald [98]. The four component includes: First, *the illusion of being in a stable spatial place*. It means the illusion of place has character of the actual space, so that people perceive position, area, and size of objects in front of them fit together naturally in the space and that the illusion of the space is stable. It is possible if objects presented in virtual space are consistent across a user's sensory modalities, for example there is no restrict the view and the user has freedom to move around space. Second, *the illusion of self-embodiment*. It is a sense that people perceive their body in the virtual world, for example people sense when the movement of their physical body matches the movement of their virtual body. Third, *the illusion of physical interaction*, a perception that objects in the virtual space respond realistically to interactions, such as the object following the hand when grasped or objects dropping to the ground because of gravity. Fourth, *the illusion of social communication*. This is a person's perception that are able to communicate with other people or a computer agent in the virtual space, both verbally and non-verbally.

The three components: the illusion of being in a stable spatial place, the illusion of self-embodiment, the illusion of physical interaction, are chosen to create the items for measuring the presence except the illusion of social presence. It will be measured in Social presence factor in this study. The items include:

- I had a sense of being there in the exhibit rather than I saw the exhibit.
- I have a high degree of freedom to move around inside the virtual exhibit.
- I feel the visual aspect of the virtual exhibit involves me.
- I feel the audio aspect of the virtual exhibit involves me.
- I perceive my body in the virtual exhibit environment.
- I naturally interact with the object in the virtual exhibit

2) Co-Presence refer to sense of being in the VE together. The items of this factor derived from the concept of copresence proposed by Nowak and Biocca [150], the copresence exist when people report they perceive other people and felt other people perceive them. This factor aims to measure how players are connected in the VE. The item include:

- I feel my partner perceive me.
- I am aware of my partner in the virtual exhibit.
- I do not feel alone in the virtual exhibit.

3) Social presence refers to a system supporting players' communication and discussion ability. This factor is derived from the concept of social presence proposed by Nowak and

Biocca [150], in which social presence is used to evaluate a player's ability to connect and interact with other people via the telecommunication system, and the players feel that the system's ability to provide them to perceived other. To measure the system's ability to connect people, which will measure the ability of the system to provide a social interaction mechanism for visitors to effectively and clearly communicate. The items created are based on a theory of communication to evaluate the features of virtual body (VB) design, including both verbal and nonverbal communication [61]. The items below are designed to measure the effectiveness of the VB mechanism in communicating scientific content in the VE, allowing a player to understand the message, indicate direction, and perceive emotion. The items are:

- I felt that my partner seemed alive in the virtual exhibit. (VB real)
- My partner understood what I meant when I say. (understand the message)
- My partner correctly understood the object that I told. (pointing, direction an object)
- I perceived my partner's emotions. (emotion expression, facial expression)

4) Engagement this factor intends to measure how the exhibit attract and stimulates players learn from the exhibit. It is a significant factor in a visitor's experience of using technology in museums [152]. The items are:

- I felt enjoyed playing with the exhibit.
- I felt engaged with the exhibit.

5) Knowledge exchange

This item measures the extent to which an exhibit provides an opportunity for visitors to learn and exchange knowledge. Because the exhibit is ultimately a learning medium, players should obtain some knowledge. An aim of the exhibit is to provide social interaction, with the intent of allowing players to exchange their knowledge without interruption. It is suggested by Bitgood [20] the social facilitation design approach, which aims to exhibit, provide or stimulate visitors to have social interaction among visitors, and it can measure social impact, for example, a visitor asking a question, a visitor giving information to other, pointing to explain, give instructions, etc. So, this factor will measure the knowledge exchange between players. The items are:

- I gained knowledge from my partner during I play in the exhibit.
- My partner did not interrupt my learning from the exhibit.

The qualitative measurement uses open ended question in an interview after each pair of participants finish their experience with each design cases.

6.3.6 Procedure

The three design cases are set up in two rooms. Figure 6.5 shows an example of the devices and room setup. The pair of participants are separated in different rooms and assigned names P1 and P2. The experimenter describes the purpose and process of the study and then participants sign a consent form. The first step in the study is, do a general background information questionnaire. Second, they play with the exhibit for each design cases, one by one, in an order assigned by the experimenter, with an equal random order using Latin Square, such that P1 and P2 are equally likely to use VR and PC. Figure 6.6 shows the assigned order to each pair of participants. Third, they provide user feedback via questionnaire and have a short interview about their experience with each design case. Fourth, after they finish their experience with all three design cases, the experimenter interviews them regarding their overall experience with the three design cases. The experimenter records video during a participant's interaction with the exhibit.

Figure 6.5 The devices and room setup for the experiment. a) A set of devices for each participants includes a set PC with a game installed, a laptop for video conference, and a VR headset. b) A room and play area for VR. c) Zoom is used for communication and observation.

Design cases	Pattern 1	R1	R2	Pattern 2	R1	R2
D1: Single player	D1-1	VR	PC	D1-2	VR	PC
		P1	P2		P2	P1
D2: Multiplayer-Symmetric	D2-1	VR	VR	D2-2	VR	VR
		P1	P2		P1	P2
D3: Multiplayer-Asymmetric	D3-1	VR	PC	D3-2	VR	PC
		P2	P1		P1	P2

Participants	1st	2nd	3rd	Participants	1st	2nd	3rd
Pair 1	D1-1	D2-1	D3-1	**Pair 7**	D1-2	D2-2	D3-2
Pair 2	D1-1	D3-1	D2-1	**Pair 8**	D1-2	D3-2	D2-2
Pair 3	D2-1	D1-1	D3-1	**Pair 9**	D2-2	D1-2	D3-2
Pair 4	D2-1	D3-1	D1-1	**Pair 10**	D2-2	D3-2	D1-2
Pair 5	D3-1	D1-1	D2-1	**Pair 11**	D3-2	D1-2	D2-2
Pair 6	D3-1	D2-1	D1-1	**Pair 12**	D3-2	D2-2	D1-2

Figure 6.6 The assigned sequence of design cases for participants. P1= participant 1, P2 = participant 2 in each pair, R1= Role Player 1, R2= Role Player 2.

6.4 Result

6.4.1 Overall User Experience of Each Design

6.4.1.1 Overall User Experience by Item D1: Single Player

In design D1 players interact with the exhibit alone, with player R1 using VR and player R2 using PC. Figure 6.7 shows participant response (as an overall percentage) to the questionnaire per item. More than 70% of participants give positive feedback (agree and strongly agree) to the audio aspect of the virtual exhibit (item3). 62% felt they interacted naturally with the objects in the exhibit. On another hand, more than one-third gave negative feedback (strongly disagree and disagree) on item 2: *I have a high degree of freedom to move around inside the virtual exhibit,* and half of the participants did not enjoy and engage with the exhibit.

Figure 6.7 User response (as overall percentages) to the questionnaire per items of D1.

6.4.1.2 The Overall User Experience by Item D2: Symmetric Multiplayer

In design D2, players play together in the virtual exhibit and use the same device, VR-VR. Figure 6.8 shows the participants' response (as an overall percentage) to the questionnaire. More than 70% of participants gave positive feedback to D2 on almost all items. Only one item: item 2 *I have a high degree of freedom to move around inside the virtual exhibit* had a positive response lower than 50% percent. More than half of participants strongly agreed that they enjoy playing with the exhibit (item14: 62.50%), felt engaged with the exhibit (item15: 54.17%), and felt the visual aspect of the virtual exhibit involved them (item2: 54.17%). More than 95% of participants did not feel alone in the virtual exhibit.

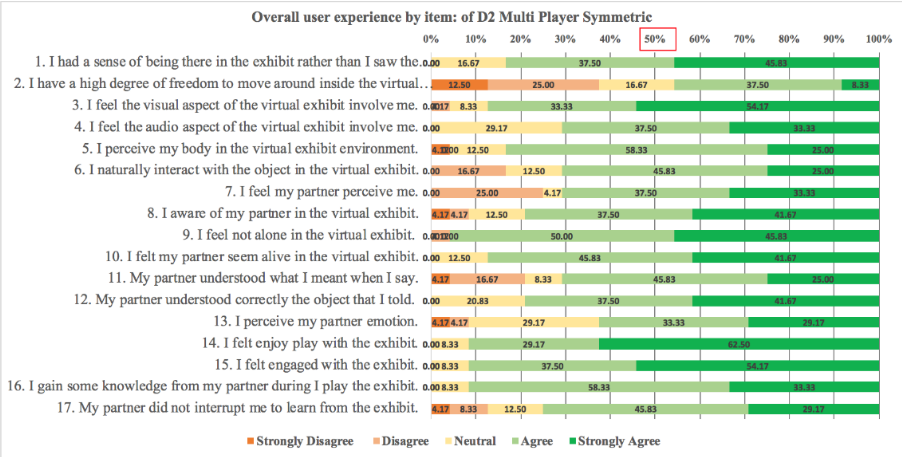


Figure 6.8 User responses (as an overall percentage) to the questionnaire per item of D2.

6.4.1.3 The Overall User Experience by Item of D3: Asymmetric Multi Player

For Design 3, players play together in the virtual environment but using difference devices; the player in role 1 uses VR (R1-VR) and the player in role 2 uses PC (R2-PC). Figure 6.9 shows the participants' responses (as an overall percentage) to the questionnaire per items. 6 items received 60% or more positive feedback, including item17: *My partner did not interrupt me to learn from the exhibit* (66.66%), item9: *I feel not alone in the virtual exhibit* (66.32%), item14: *I felt enjoy playing with the exhibit* (62.50%), item4: *I feel the audio aspect of the virtual exhibit involve me (62.50%),* item15: *I felt engaged with the exhibit (62.17%),* item16: *I gain some knowledge from my partner while I play the exhibit* (62.17%), and item8: *I am aware of my partner in the virtual exhibit* (62.17%). Of concern, half of the participants gave negative feedback on item5, indicating that they did not perceive their body in the virtual exhibit environment, while 37.50 % of participants gave negative feedback on item 2 and item 12.

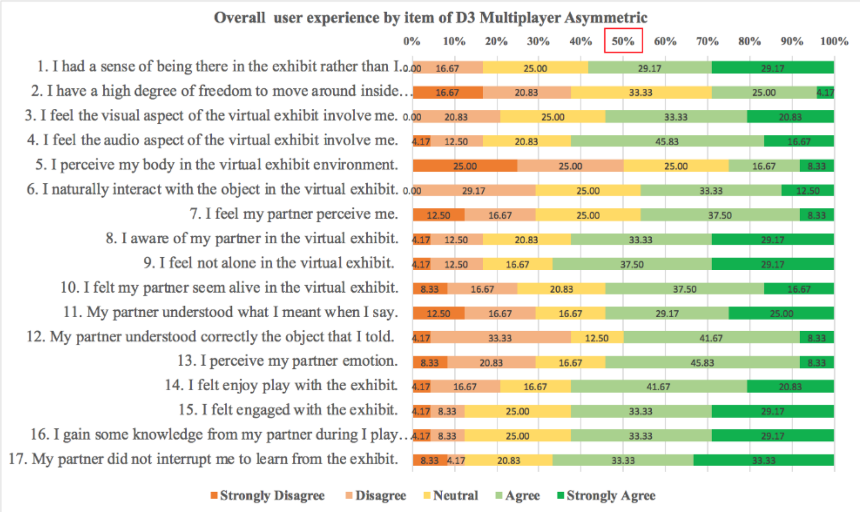


Figure 6.9 User response (as overall percentage) to the questionnaire per item of D3.

6.4.1.4 The overall user experience by items comparing the role of player1 (R1-VR) and the role of player2 (R2-PC)

Figure 6.10 shows the participants responses (as an overall percentage) to the questionnaire per item and compares R1 and R2. Most of R1, those who used VR, gave positive feedback on all items, with feedback higher than R2, those who used PC, in D1 and D3. This is especially true on item 1, sense of being there in the exhibit for D1 (R1-VR 91.67%, R2-PC 33.33 %).

The result of D3 shows more than a 50% difference between R1 and R2 on item 1 (R1-VR 83.34%, R2-PC 33.34%), on item 3 felt the visual aspect of exhibit involve them (R1-VR 83.33%, R2-PC 25.00%) and on item 4 felt the audio aspect of exhibit involve them (R1-VR 91.67%, R2-PC 33.30%). None of R2-PC in D3 *give positive feedback on item 5: I perceived my body in the virtual exhibit environment*. In contrast, almost all items on D2 received very hight positive feedback, with a similar trend of feedback between R1 and R2 except for item 3 regarding visual aspect and item 2 regarding degree of freedom to move around exhibit slightly different.

In summary, the statistical results show D2: multiplayer, in which both players use VR, provided the best user experience on all items. D3: multi-player, which is asymmetric in that players use a different device; one player uses VR, and another uses PC, decreasing user experience quality. However, D3 received a higher overall quality of user experience in that almost all items of D3 received more than 50% positive feedback.

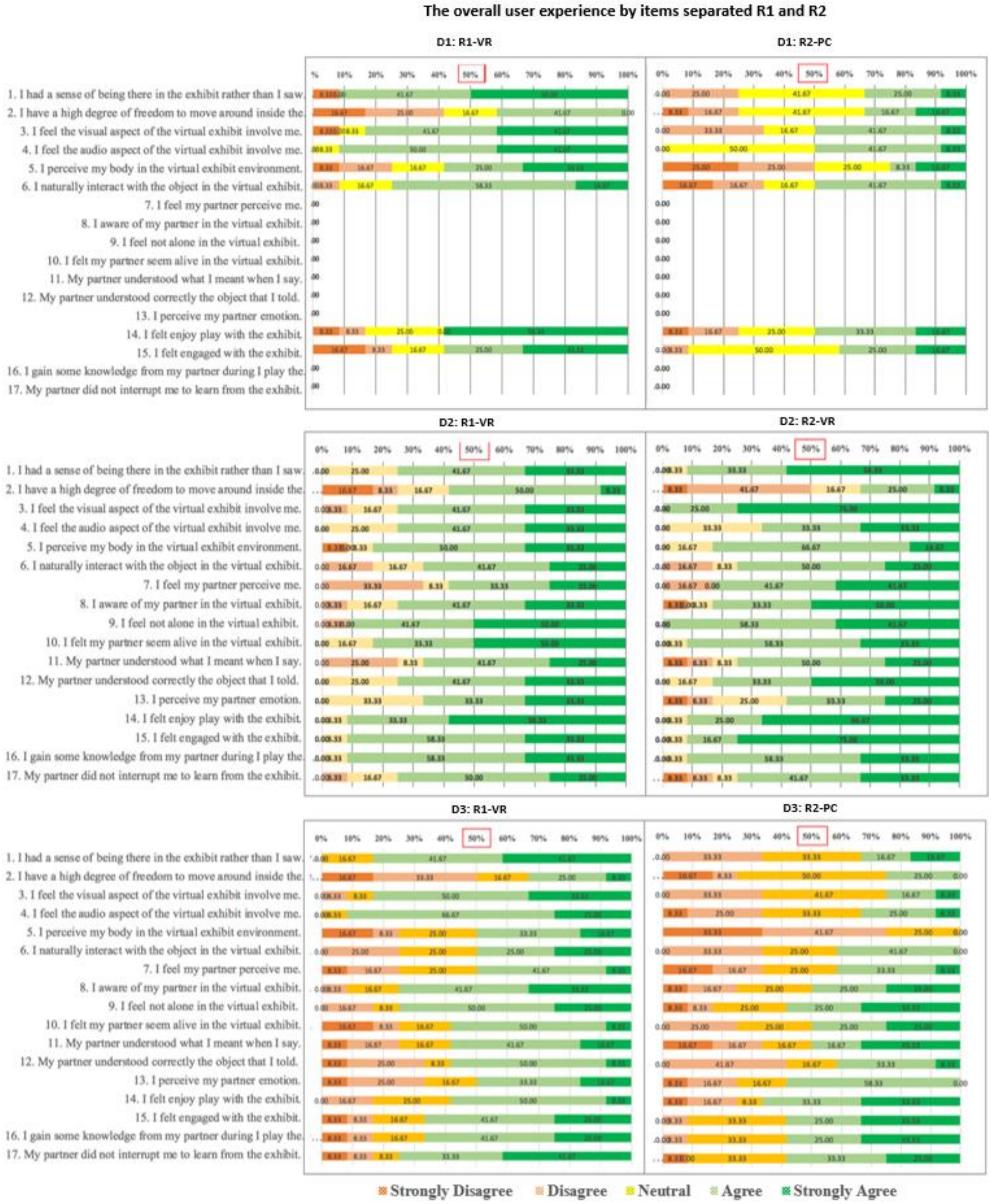


Figure 6.10 User responses (as an overall percentage) to the questionnaire per item of D3 and for separate participant roles.

6.4.2 The Overall User Experience by Factors

Figure 6.11 shows the mean value of the overall user experience by each design factor. The five factors include factor 1 Presence, factor 2 Copresence, factor 3 Social Presence, factor 4 Engagement, and factor 5 Knowledge exchange. The radar chart in figure 6.11 a) shows a comparison of each factor between D1, D2 and D3. The statistical result shows D2 received the highest on all factors, with Factor 1 M=2.92 (SD=0.58), Factor 2 M=3.08 (SD=0.70), Factor 3 M=3.00 (SD=0.55), Factor 4 M=3.50 (SD=0.57), and Factor 5 M=3.06 (SD=0.60). Another point to mention is that D1 received a higher mean value than D3 on Factor 1-Presence, where D1: M=2.49 (SD = 0.82) and D3: M =2.25 (SD= 0.75).

The radar chart in Figure 6.11 b) compares the mean value between R1-VR and R2-PC of D1. The statistical result show that R2 received a lower mean value than R1 on Factor 1 – Presence, with R1 M=2.82 (SD= 0.80) and R2 M=2.15(SD = 0.74), Factor 4-Engagement, with R1 M= 2.71 (SD=1.30) and R2 M=2.42 (SD =0.90).

The radar chart in Figure 6.11 c) compares the mean value between R1-VR and R2-VR of D2. The result shows that when both R1 and R2 use VR in the experiment, the mean values are quite similar on all factors.

The radar chart in Figure 6.10 d) compares the mean value between R1-VR and R2-VR of D3. R2-PC received a lower mean value than R1 on all four factors except for factor 3 - Social presence, which received the same value as R1-VR (R1: M= 2.29, SD=1.18, R2: M=2.29, SD=0.89). A point to mention for D3 is that R2-PC dramatic decrease in the sense of presence compared to R1-VR, with mean values Factor 1 – Presence of R1-VR: M= 2.67 (SD=0.83), and R2-PC M=1.83 (SD=0.73).

In summary, the statistics show D2 received the best user experience on all factors, and R1-VR provided a better user experience than R2-PC in D1 and D3, except for factor 3-Social presence of D3, where R1-VR and R2-PC offer the same quality of user experience. The following section will find a significant difference between design cases of each factor.

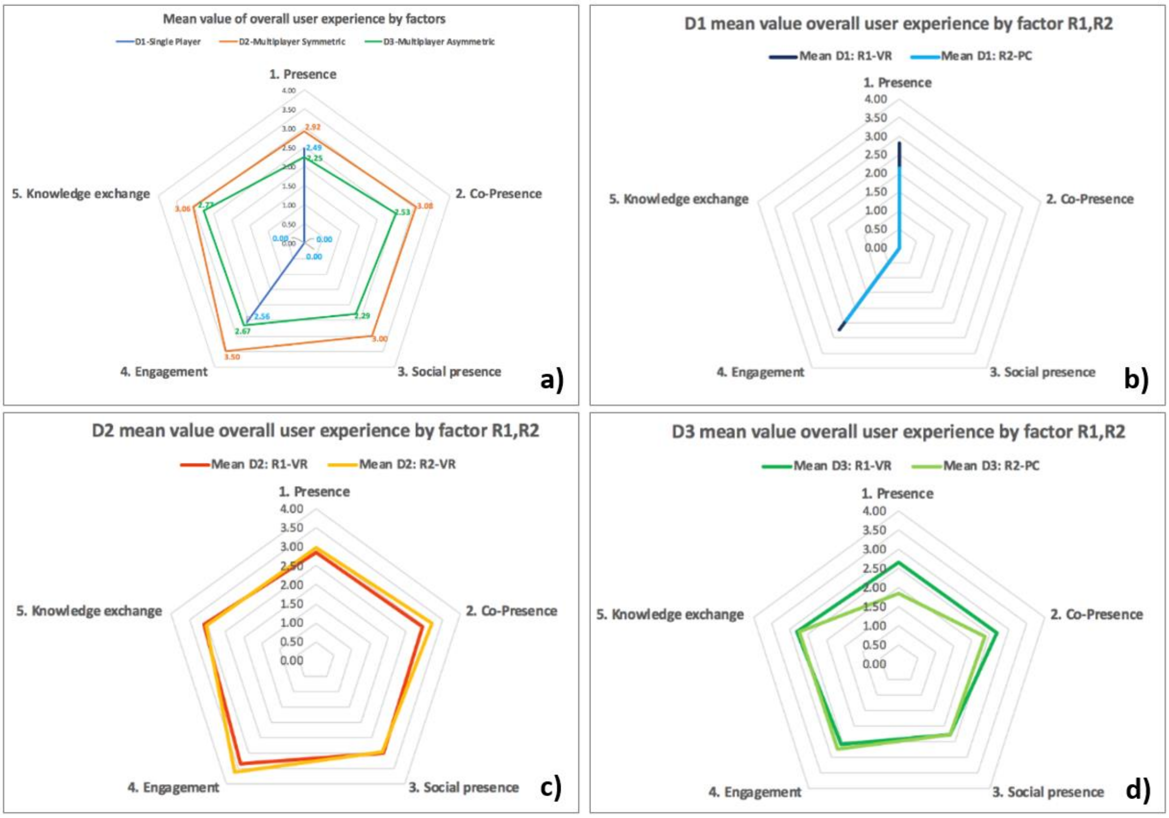


Figure 6.11 The mean value of overall user experience by factors. a) Comparison of design cases D1, D2 and D3 b) Comparision of roles R1 and R2 of D1 c) Comparision of role R1 and R2 of D2 d) Comparision of roles R1 and R2 of D3.

6.4.3 Null Hypothesis Significance Testing

This section will show the result finding a significance of the mean values of user experience between D1-single player, D2-symmetric multiplayer, and D3- asymmetric multiplayer by using the Friedman non-parametric test followed by post hoc analysis with Wilcoxon. The summary of the results is shown in table 6.1. The result of each factor is discussed below.

Table 6.1 A summary statistical significance test results of each factor.

Factors	Nonparametric test with Friedman (α = 0.05)								Post hoc test with Wilcoxon (p < 0.017)		
	χ2	p	Median (IQR)			Mean Rank			D1 vs. D2	D1 vs. D3	D2 vs. D3
			D1	D2	D3	D1	D2	D3			
Factor 1 Presence	7.80	0.02	2.5000 (1.71 to 3.29)	2.8300 (2.50 to 3.30)	2.3300 (1.71 to 2.79)	1.88	2.44	1.69	× 0.025	× 0.403	✓ 0.001
Factor 2 Co-presence	40.64	0.00	0.0000 (0.00 to 0.00)	3.0000 (2.67 to 3.9175)	2.5000 (2.00 to 3.33)	1.00	2.73	2.27	✓ 0.000	✓ 0.000	✓ 0.012
Factor 3 Social presence	38.00	0.00	0.0000 (0.00 to 0.00)	3.0000 (2.75 to 3.4375)	2.3750 (1.5625 to 3.00)	1.02	2.71	2.27	✓ 0.000	✓ 0.000	✓ 0.010
Factor 4 Engagement	18.49	0.00	2.5000 (2.00 to 3.875)	3.5000 (3.00 to 4.00)	3.0000 (2.125 to 3.500)	1.67	2.65	1.69	✓ 0.004	× 0.686	✓ 0.001
Factor 5 Knowledge exchange	40.09	0.00	0.0000 (0.00 to 0.00)	3.0000 (2.500 to 3.500)	3.0000 (2.00 to 3.500)	1.00	2.63	2.38	✓ 0.000	✓ 0.000	× 0.093

✓ a significate different, × a no significant different

6.4.3.1 Factor 1 Presence

There was a statistically significant difference in user experience on factor 1- Presence, depending on the design cases used to facilitate players interaction in the exhibit, $\chi2(2) = 7.80$, $p = 0.02$. Post hoc analysis with Wilcoxon signed-rank tests was conducted with a Bonferroni correction applied, resulting in a significance level set by $p < 0.017$. Median (IQR) Presence levels for the D1, D2 and D3 running tests were 2.50 (1.71 to 3.2), 2.83 (2.50 to 3.33), and 2.33 (1.71 to 2.79), respectively. There were significant differences between D3 and D2 running trials (Z = -3.311, $p = 0.001$). However, there were no significant differences between D2 and D1 running trials (Z = -2.239, $p = 0.025$) and between D3 and D1 running trails (Z = -0.837, $p = 0.403$).

6.4.3.2 Factor 2 Copresence

There was a statistically significant difference in user experience on factor 2 - Copresence, depending on the design cases used to facilitate players interaction in the exhibit, $\chi2(2) = 40.638$, $p = 0.00$. Post hoc analysis with Wilcoxon signed-rank tests was conducted with a Bonferroni correction applied, resulting in a significance level set by $p < 0.017$. Median (IQR) Copresence levels for the D1, D2 and D3 running test were 0.00 (0.00 to 0.00), 3.00 (2.67 to 3.91), and 2.50 (2.00 to 3.33), respectively. There were significant differences between D3 and D2 running trials (Z = -2.522, $p = 0.012$), between D2 and D1 running trials (Z = -4.307, $p = 0.00$), and between D3 and D1 running trails (Z = -4.293, $p = 0.00$).

6.4.3.3 Factor 3 Social Presence

There was a statistically significant difference in user experience on factor 3 - Social presence, depending on the design cases used to facilitate players interaction in the exhibit, $\chi2(2) = 38.00$, $p = 0.00$. Post hoc analysis with Wilcoxon signed-rank tests was conducted with a Bonferroni correction applied, resulting in a significance level set by $p < 0.017$. Median (IQR) Social presence levels for the D1, D2 and D3 running tests were 0.00 (0.00 to 0.00), 3.00 (2.75 to 3.43), and 2.37 (1.56 to 3.00), respectively. There were significant differences between D2 and D1 running trials (Z = -4. 307, $p = 0.000$), between D3 and D1 running trails (Z = -4.209, $p = 0.00$), and between D3 and D2 running trials (Z = -2.573, $p = 0.010$).

6.4.3.4 Factor 4 Engagement

There was a statistically significant difference in user experience on factor 4 – Engagement, depending on the design cases used to facilitate players to interaction in the exhibit, $\chi2(2) = 18.487$, $p = 0.00$. Post hoc analysis with Wilcoxon signed-rank tests was conducted with a Bonferroni correction applied, resulting in a significance level set by $p < 0.017$. Median (IQR) Engagement levels for the D1, D2 and D3 running tests were 2.50 (2.00 to 3.875), 3.50 (3.00 to 4.00), and 3.00 (2.125 to 3.35), respectively. There were significant differences between D2 and D1 running trials (Z = -2.869, $p = 0.004$), and between D3 and D2 running trails (Z = -3.292, $p = 0.001$). But there were no significant differences between D3 and D1 running trails (Z = -0.405, $p = 0.686$).

6.4.3.5 Factor 5 Knowledge exchange

There was a statistically significant difference in user experience on the factor 5 - Knowledge exchange depending on the design cases used to facilitate players interaction in the exhibit, $\chi2(2) = 40.091.487$, $p = 0.00$. Post hoc analysis with Wilcoxon signed-rank tests was conducted with a Bonferroni correction applied, resulting in a significance level set by $p < 0.017$. Median (IQR) Engagement levels for the D1, D2 and D3 running test were 0.0 (0.00 to 0.0), 3.00 (2.50 to 3.50), and 3.00 (2.00 to 3.50), respectively. There were significant differences between D2 and D1 running trials (Z = -4.315, $p = 0.00$), and between D3 and D1 running trails (Z = -4.321, $p = 0.00$). But there were no significant differences between D3 and D2 running trails (Z = -1.677, $p = 0.093$).

6.4.3.6 Summary of the Hypothesis Test

Hypothesis 1: There is no difference in the feeling of presence between single player (D1), symmetric multiplayer connection (D2), and asymmetric multiplayer connection (D3).

The statistics show significant differences in the sense of presence between D2 and D3. And there was no significant difference in the sense of presence between D1 and D2 and between D1 and D3. Hypothesis 1 is rejected because of the significant difference between D2 and D3. In which, participants reported a significantly greater sense of presence in symmetric multiplayer compared to asymmetric multiplayer.

Hypothesis 2: There is no difference in the efficiency of social interaction for communication between a symmetric multiplayer connection and asymmetric multiplayer connection.

To assess the hypothesis, will compare the factors that measure communication quality, which include factor 2 Copresence and factor 3 Social presence. The statistical results show there was a significant difference between D2 symmetric multiplayer connection and D3 asymmetric multiplayer connection on copresence and social presence. The symmetric multiplayer connection offers greater sense of copresence and social presence than the asymmetric multiplayer connection so that this hypothesis is rejected based on this experiment. However, the result by item shows that some aspects of D3 decrease quality levels from D2. This issue will be discussed in the next section.

Hypothesis 3: There is no difference in learning experience between the exhibits which use multiplayer designs (D2 symmetric and D3 asymmetric) and those that use single player design (D1) with respect to exchanging knowledge, engaging players to play with the exhibit and decreasing loneliness.

To assess this hypothesis, factor 4 Engagement, factor 5 Knowledge exchange, and factor 3 Copresence is compared. The statistical results show a significant difference on factor 4 which show different between D1 and D2, indicating multiplayer design D2 VR-VR better engages players than single player design. In factor 5 Knowledge exchange the results show a significant difference between D1 and D2, and between D1 and D3. This suggests multiplayer design players have increased exchange of knowledge with their partner. Finally, factor 3 Copresence, where the results show a significant difference between D1 and D2, and between D1 and D3. Also, the results by item show that D2 and D3 receive positive feedback on item 9 (user do not feel alone in the virtual exhibit), where D2 95.83% and D3 66.67%. From these results, this hypothesis is rejected as the learning experience from the exhibit differs between single player design D1 and multiplayer design D2, D3, in which multiplayer provides improved exchange of knowledge, is more engaging, and decreases loneliness in VE.

6.4.4 Qualitative Data the Result from the Interview.

A semi-structured interview was conducted after a participant experienced each design case and again after they had experience with all three design cases. After they had experience with each design, they were asked the same question, and after they had experience with all three designs (D1, D2, and D3), they were asked about their overall experience. The interview was conducted using the Zoom video conference application, with each pair of participants interviewed at the same time. The interview used P1 and P2 to represent players in each pair. A summary of the questions used in the semi-structured interview is shown in table 2.

Table 6.2 The questions in the semi-structured interviews.

Interview Question
Experience and issue using each design cases
1. How is it easy or difficult for you to play with this interactive exhibit?
2. Do you have any problem during play with this interactive exhibit?
3. Do the virtual body in the virtual word is important for you when you play this exhibit?
Overall experience
1. Which design of interactive exhibit do you prefer for play with your friend?
2. Which feature do you like in the design of the interactive exhibit?
3. Is the visual information (text, animation) in the interactive exhibit is clear for you to read?
4. Is the sound information in the interactive exhibit is clear for you?
5. Is the layout, size, and position of the object in the game (virtual environment) appropriate design?
6. Which virtual body (VB) feature helped you understand what your partner said?
7. Which the game style that you like for this exhibit, and why?
8. Other recommendations?

All interview records are automatically transcribed into text files using the Otter.ai program. Then, all the transcript files are corrected for each sentence by researcher. After that, all edited transcript files are analysed using NVivo software for coding and themes analysis, as suggested by Bopp et al. [23], Gowler and Iacovides [74], Braun and Clarke [24], Terry and Hayfield [209]. The final themes are shown in figure 16.11. Illustrative quotes are labelled with two patterns. Pattern one is the quote of players' opinions on each design after experiencing each case. It displays the pair number, the design cases, and device used. For example (Pair 6, D1, P1-VR) means the quote is from participant pair number 6, who played with D1 and used VR to interact with the exhibit. Pattern two is the quotes from players' feedback on their overall experience after experiencing all the three design cases. It displays the pair number, the label “overall", and the participant number. For example, (Pair 10, overall, P1-U19) means the quote is from participant pair number 10, from the overall experience, and participant number U19.

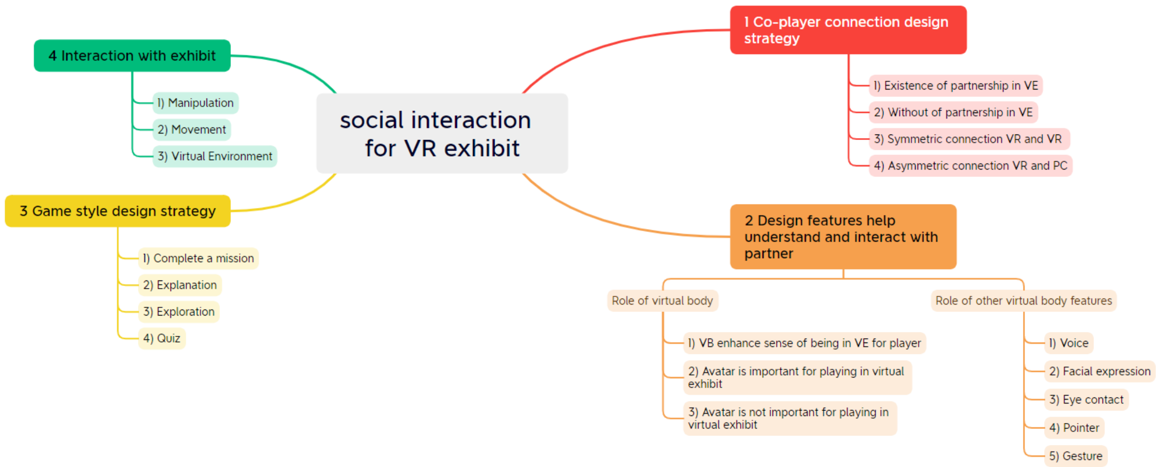


Figure 6.12 The final thematic map representing the four keys in influencing social interactions in the VR exhibit.

6.4.4.1 Theme 1: co-player connection design strategy

This theme focuses on each design method for connecting players, both single players and multiple players, and the effect on players’ experience. This theme mention the benefits of partnership in VE and the difference in user experience between symmetric and asymmetric connections. There are four sub-themes to mention.

1) Existence of partnership in VE: having a partner in the VE is beneficial for many reasons. For example, players feel good and a sense of togetherness in the VE when they see their partner avatar (Pair 2, D2, P2-VR). The situation in the VE is more realistic when players play together and are able to communicate with a partner (Pair 12, overall, P1-U21). The players reported a sense of realisms when standing next to a partner, hearing their voice, and waving hands to interact with the partner (Pair 9, overall, P1-U17). And another good point of having a partner in the VE is that it simulates the situations of visiting a physical exhibit in a museum where there is a need discuss with someone (Pair 2, D2, P2-VR). Partners offer help to players (Pair 4, overall, P2-U08) and help each other play games in the exhibit, making a mission easier to complete (Pair 2, D2, P1-VR). In contrast, having a partner in the VE sometime can resist a player from playing exhibit “…when I’m doing my mission, he blocked me I couldn’t pull him out…” (Pair 4, D3, P1-PC), especially in a small area to access the exhibit. The virtual world did not have a function to send a signal to a partner to stop play and hand over a control to give someone else a chance.

2) Without partnership in VE: experiencing a VE without a partner decreases the quality of the social experience. For instance, players felt lonely when they played exhibits, enjoyable social activities like virtual celebrations are impossible, and the lack of communication and discussion lead to decreased interest (Pair 6, D1, P1-VR). It is challenging to complete a mission in the game without a partner (Pair 8, overall, P2-U16).

3) Symmetric connection, VR and VR cooperative play: players both use a VR device and play exhibit together in a symmetric connection. Participants reported they have a sense of being there together and the feeling that their partner was beside them and in the same environment (Pair 10, overall, P2-U16) (Pair 12, overall, P1-U23) (Pair 12, overall, P2-U24) (Pair 5, overall, P1-U09). Players felt the experience was more realistic when using this mode of play (Pair 9, overall, P2-U18). They reported a more enjoyable and fun experience (Pair 6, overall, P1-U11) (Pair 2, D2, P2-VR) (Pair 3, overall, P2-U06), in part because their movement was quite natural (pair 7, overall, P2-U14), and it was easy to play exhibit (Pair 8, overall, P2-U16) (Pair 1, overall, P2-U02). Finally, seeing their and their partner's avatars was a source of entertainment (Pair 4, overall, P2-U08).

Symmetric connection VR-VR provides a good experience with improved communication. It is easier to use and better than asymmetric VR-PC (Pair 11, D2, P2-VR) (Pair 8, D2, P2-VR). The communication is clear (Pair 9, D2, P1-VR) and amazing (Pair2, D2, P1-VR). And another good aspect of symmetric VR-VR is that it is easy to interact with a partner, so it induces more interaction between players (Pair 11, overall, P1-U21). Players can interact with partners the same as in the physical world, for example, it is possible to shake hands (Pair 5, overall, P1-U09).

4) Asymmetric connection, VR and PC cooperative play: in the asymmetric connection design, players access the VE from different platforms, but can still communicate, providing some benefits for social interaction. For example, one of the participants mentioned she can see and communicate with her partner but it is not optimal (Pair 6, overall, P1-U11). Asymmetric connection PC-VR players were able to play together and help each other complete a mission (Pair 8 overall, P1-U15), and a player using the PC was able to offer to help a partner using VR (Pair 4, overall, P1-U07). However, the quality of social interaction experience was decreased relative to the symmetric connection.

Players felt unconnected to their partner when using the asymmetric connection VR-PC (Pair 3, D3, P2-VR). It made players feel separated and feel as though they were playing with exhibits in a different environment. Less connection with their partner (Pair 10, overall, P2-U20) (Pair 5, overall, P2-U10), especially, when playing exhibit by mouse and keyboard, made players feel more disconnected (Pair 2, D2, P1-VR) and less engaged with the exhibit (Pair 10, overall, P2-U20) (Pair 10, overall, P1-U19). Some participants found the PC difficult to control. In addition, the interaction via PC connected with VR resulted in an unnatural experience (Pair 9, overall, P2-U18). According to a participant said, "…we can't see what's a movement in the PC, just like a robot moving around." (Pair 9, overall, P1-U17).

6.4.4.2 Theme 2: Design Feature Help Understand and Interact with Partner.

This theme emphasizes how players understand their partner, including the virtual body (VB) feature and player action related to VB in the virtual exhibit. This theme will describe how players use VB for communication and interaction in the VE.

Role of virtual body

1) VB enhances sense of being in VE: the virtual body or avatar represents the player in the VE and helps players perceive themselves in the VE so that it makes them feel alive in VE (Pair 10, D1, P2-VR) and as though they really are present in the VE (Pair 1, D1, P2-PC) (Pair 12, D2, P2-VR) (Pair 2, D2, P1-VR). However, players only see their virtual hand during play exhibit via VR (Pair 4, D3, P2-VR) (Pair 5, D3, P2-VR), so they cannot imagine the appearance of their VB (Pair 3, D2, P2-VR). One participant stated that he might feel disconnected if he did not see the character of his VB (Pair 2, D3, P1-PC). The mirror is set up in the VE to solve this problem, allowing players to see their VB characters and provide a sense of being in the VE (Pair 2, D1, P1-VR). The reflection on the mirror shows players that their VB moves according to their action and is more engaging (Pair 4, D1, P2-PC) (Pair 9, overall, P2-U18) (Pair 4, D2, P2-VR).

2) Avatar is important for playing in virtual exhibit: VB provokes players to feel as though they are part of the game (Pair 7, D1, P2-VR), and it is significant when playing the exhibit with a partner (Pair 9, D3, P1-VR) (Pair 9, D3, P2-PC). Players recognize the direction of their partner in the VE by their partner's virtual body, and as a result, players feel they are in the VE together (Pair 7, overall, P1-U13) (Pair 2 D3, P1-PC) (Pair 10, D3, P2-PC). The VB is important for collaboration between players in the VE, and VB provide a cue for the player to know what their partner is doing (Pair 7, D2, P2-VR) and where they are in the VE (Pair 11, D3, P1-VR) (Pair 12, D3, PC). This consequence makes collaboration and communication with partners easier (Pair 12, D3, P2-PC). In addition, VB is a necessary mechanic to support social interaction in VE occur, for instance, it allows players to be able to celebrate with a partner "…we can like hi-five when we win" (Pair 11, D2, P1-VR). It also allows the player to be able to better advise their partner (Pair 11, D2, P2-VR).

3) Avatar is not important for playing in virtual exhibit : VB is not essential when playing alone (Pair 4, D1, P2-PC), because players cannot perceive themselves when playing alone, but players perceive other players' avatars when playing together (Pair 9, D2, P2-VR). VB is not significant if VB does not appear and players do not have a sense of their VB (Pair 1, D2, P1-VR), especially when playing in first-person perspective on PC (Pair 4, D1, P2-PC), making the player feel less of VB (Pair 12, D1, P1-PC) (Pair 7, D3, P2-PC). VB is less important and unfunctional when playing with the PC screen (Pair 3, D1, P2-PC) (Pair 4, D1, P2-PC) because players do not use the VB to interact with the game (Pair 9, D2, P2-VR).

Role of other virtual body feature

Other design features that help to communicated with a partner, in addition to VB are voice, facial expression, eye contact, pointer, and gesture. Benefits of these features are detailed below.

1) Voice is the main feature for communication in VE (Pair2, overall, P2-U04) (Pair3, overall, P1-U05). While players play, they focus on interacting with the game, so players pay less attention to their partner's virtual body (Pair4, overall, P1-U07) (Pair 1, overall, P1-U01)

2) Facial Expression was not necessary to understand the partner's message but can stimulate the player's enjoyment (Pair 2, overall, P1-U03). Players rarely looks at their partner's VB (Pair 7, overall, P2-U14) because they stand side by side and find it difficult to turn face to face with their partner (Pair 6, overall, P1-U11). However, the system does not provide a function for facial expression, so players are unable to utilise this aspect of communication (Pair 3, overall, P2-U06) (Pair 4, overall, P2-U08) (Pair 9, overall, P2-U18).

3) Eye contact was rarely used to communicate in the VE. The reason is the same as facial expression, with players focusing on the mission rather than making eye contact with the partner (Pair1, overall, P1-U01). Additionally, players typically stand face to the steam engine (the main object in the exhibit) and stand in the same direction as their partner (Pair7, overall, P2-U14).

4) Pointer helps players understand their partner (Pair 2, D2, P1-VR) without saying anything (Pair 3, D2, P2-VR). Players use the pointer to help to explain their thought to their partners (Pair 1, overall, P2-U02) (Pair 6, overall, P1-11). In addition, the pointer is used to indicate an object to help their partner clearly understand their message (Pair 8, overall, P2-U16) (Pair 10, overall, P1-U19) (Pair 11, overall, P1-U21). This proved particularly beneficial when a player was unable to hear the partner's voice clearly. The pointer indicates the status of interaction with an object, red or white, to indicates if the player is able to interact with the object. However, a participant mentioned using a laser pointer to grab an object feels unnatural (Pair 3, overall, P1-U05).

5) Gestures, such as hand and body movements, create more realism and enjoyment, but are not necessary to understand the partner's message (Pair 2, overall, P1-U03). Players waved hands to greet partners (Pair 10, overall, P2-U20) (Pair 7, overall, P1-U17) and to teach their partners how to play the game (Pair 4, overall, P1-U07). The hand movement allows them to interact with their partner, for example giving a hi-five (Pair 3, overall, P2-U06) (Pair 6, overall, P2-U12).

6.4.4.3 Theme 3: Game Style Design Strategy

This theme focused on the advantages and disadvantages of the four game-tyles: complete a mission, explanation, exploration, and quiz.

1) Complete a mission: players felt engaged when attempting to complete a mission with a friend (Pair 5, overall, P2-U10) (Pair 10, overall, P2-U20), reported the exhibit was fun (Pair 11, overall, P2-U22), and that the mission challenged them (Pair 1, overall, P1-U01). This game style allowed a player to share information with a partner (Pair 2, overall, P2-U04). Players enjoyed that the system enabled them to control the engine (Pair 2, overall, P1-U03) (Pair 3, overall, P2-U06) and felt good when succeeding (Pair 8, overall, P2-U16). However, some participants disliked this game style when playing alone, especially on the PC (Pair8, overall, P2-U16).

In term of learning, a mission helped players check their understanding of the content of the exhibit (Pair 1, overall, P2-U02) (Pair 10, overall, P1-U19). Regarding the design of the mission for the game, the following factors should be considered. First, the design should provide instructions for solving the problem (Pair 7, D3, P2-PC). Second, design tasks in the mission should balance single player and multiplayer tasks. Multiple tasks for a single player are very challenging and make it difficult to complete the mission (Pair 6, D1, P1-VR) (Pair 7, D2, P2-VR) (Pair 7, overall, P1-U13).

2) Explanation: explanation game style provides players with information to understand how the engine works (Pair 1, overall, P1-U01) (Pair 10, overall, P1-U19) (Pair 4, overall, P1-U07) providing key information for all tasks in the game (Pair 1, overall, P2-U02). The animation of the engine is interesting and demonstrates the movement (Pair 2, overall, P2-U04). A participant stated that he liked the explanation because it would not be possible with the real exhibit, but in the VE, we can see what's happening inside the engine, so it is useful (Pair 9, overall, P2-U18). When designing the animation, one should consider the speed; it should not be so fast that the player cannot remember (Pair 6, overall, P2-U12) and should add a replay button so that the player can watch the animation again (Pair 10, D2, P1-U19). One disadvantage of the explanation is that it does not include an interactive component (Pair 4, overall, P2-U08).

3) Exploration: players liked the exploration mode of play because it had no time constraints (Pair 6, overall, P2-U12). It offers a free choice for players to explore each part of the steam engine (Pair 4, overall, P2-U08). Players reported that exploring an object was easy in this mode of play (Pair 8, overall, P1-U15), however exploring an object using a PC was not sufficiently involved. It felt simply like clicking buttons compared to VR (Pair 5, overall, P2-U10). A participant said this game style provided less interaction "…If I could have closed the steam valve and saw the pressure was going up in the boiler, that would have made the exploration part more interactive, more informative, and more enjoyable" (Pair 2, overall, P1-U03). Another participant suggested exploration should be the first part of the game because it tells an overview of all the components of the steam engine (Pair 10, overall, P1-U19), but more detail should be provided regarding the function of each part of the steam engine (Pair 3, overall, P1-U05) (Pair 7, overall, P1-U13) (Pair 1, overall, P2-U02).

4) Quiz: quiz stimulated players to work together to discuss finding the right answer. This mode of play was reported to be a fun way to play the game (Pair 2, overall, P2-U04). To answer the question, players need to reflect on their understanding of the exhibit's content (Pair 1, overall, P2-U02). The quiz allowed players to learn whether their answer is correct or incorrect via system feedback revealing the right answer (Pair 7, overall, P2-U14). However, players felt it was difficult to answer the question if they do not know about the topic of the exhibit beforehand (Pair 10, D2, P1-VR), so some participants suggested providing an explanation before the quiz game (Pair 7, overall, P2-U14). In contrast, some participants felt the quiz was uninteresting (Pair 7, overall, P1-U13), and that they did not enjoy answering the questions (Pair 8, overall, P1-U13) and were upset when they chose the wrong answer (Pair 8, overall, P2-U14).

6.4.4.4 Theme 4: Interaction With Exhibit

This theme focused on issues and player suggestions related to the design aspect of interactions with exhibit in the VE, to include manipulation, movement, and the virtual environment.

1) Manipulation: players reported difficulty playing with VR because it was a technology they had never used before (Pair 8, D1, P2-VR). They do not know how to move around the VE (Pair 4, D2, P2-VR). They do not know and unfamiliar with the use of the VR controller (Pair 12, D3, P1-VR) (Pair 2, D3, P2-VR) so they focused on learning how to use the controller rather than on do the mission (Pair 4, D2, P1-VR). On the other hand, players felt it was easy to play once they understand how to use the controller (Pair 3, D2, P2-VR) and became familiar with technology (Pair 12, D1, P1-PC) (Pair 12, D1, P2-VR) (Pair 6, D2, P1-VR) (Pair 1, D3, P2-VR) (Pair 8, D3, P1-VR). One thing players found challenging when interacting with game was attempting to grab an object, many players were unable to grab a coal and put it in the furnace (Pair 4, D3, P2-VR) (Pair 5, D3, P2-VR) (Pair 7, D1, P1-VR) (Pair 12, D3, P1-VR) (Pair 12, D3, P2-PC).

2) Movement: players mentioned that movement in the VE using the mouse and keyboard was difficult (Pair 10, D1, P1-PC) (Pair 2, D3, P1-PC), more so than when using the VR joystick (Pair 10, D3, P2-PC), because the movement using the mouse and keyboard was discrete (Pair 3, D3, P1-PC). Controlling movement with the keyboard and mouse was found to be unstable, too fast, or too slow (Pair 1, D3, P1-PC) (Pair 7, D3, P2-PC), and panning the view on the PC stimulated motion sickness and made one player feel dizzy (Pair 9, D3, P2-PC).

In contrast, players mentioned movement using VR was easier than with the PC (Pair 12, D1, P2-VR) (Pair 12, D2, P2-VR) (Pair 8, D3, P1-VR). Players felt to freely move around in the VE (Pair 10, D1, P2-VR) and that it was easy to navigate using the VR joystick (Pair 10, D3, P1-VR). Players preferred movement in the VE by walking rather than using the joystick because it was more enjoyable (Pair 12, D2, P1-VR) (Pair 12, D2, P2-VR) (Pair 9, D2, P1-VR) and was easier to control speed (Pair 11, D1, P2-VR) (Pair 3, D1, P1-VR). Sometimes, movement using the joystick was too fast and caused players to feel unnatural (Pair 2, D1, P1-VR). Movement by the player walking was easy and enjoyable but the physical space is limited (Pair 11, D1, P2-VR). The movement experience is enhanced if we can provide a larger space that player can move around the exhibit under their own power (Pair 2, overall, P1-U03) (Pair 4, overall, P-U08).

3) Virtual Environment: using VR, players could perceive the size of object in the VE and they felt small compared to the steam engine (Pair 6, overall, P1-U11). In contrast, players were unable perceive the size of an object in the VE when using the PC (Pair 5, overall, P2-U10). Even though the size of object may have been properly designed (Pair 7, overall, P1-U13), but the area surrounding the steam engine was to narrow (Pair 9, overall, P1-U15) "…the house should be bigger than this" (Pair 9, overall, P2-U16). This would allow players to walk around the engine and would make it more interesting (Pair 2, overall, P1-U03).

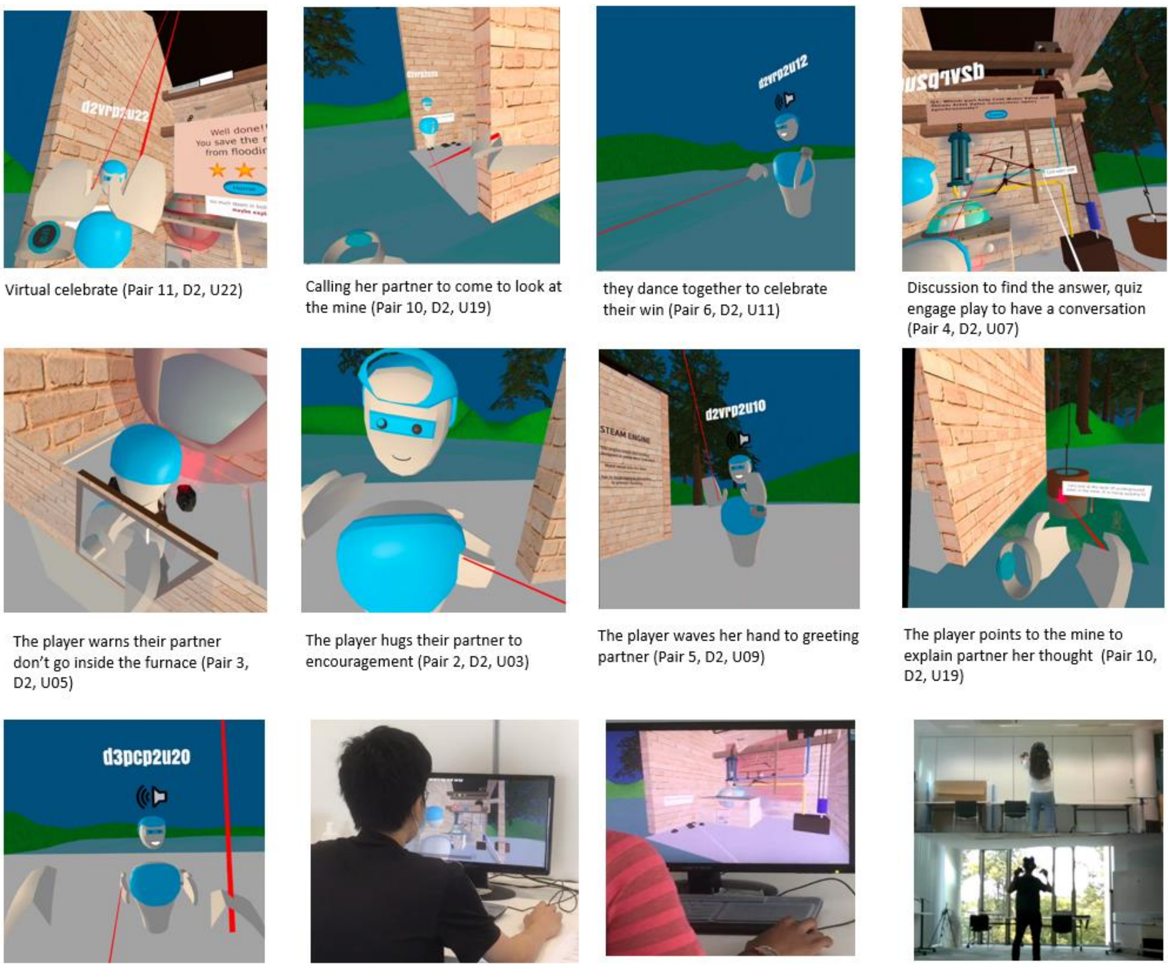
Many players mentioned that communication by voice was unclear in the VE. It was difficult to hear their partner on both VR and the PC (Pair 10, D2, P2-VR) (Pair 1, D2, P2-VR) (Pair 12, D2, P2-VR) (Pair 11, D3, P2-PC) (Pair 5, D3, P1-PC). One reason for this it that the sound of the engine was louder than players' voices (Pair 7, D2, P1-VR) (Pair 12, overall, P2-U22). Another reason given was that players did not understand the behaviour of sound in the VE, which was set up such that volume depended on distance. After they gained familiarity with the situation, the communication become more clear (Pair 8, overall, P1-

U15), however they reported that it was challenging to maintain the distance for hearing while they move around the steam engine (Pair 10, D2, P1-VR).

Players mentioned that text information on PC screen is clear (Pair 3, overall, P2-U06) but reading information on VR was difficult because text was blurry (Pair 12, overall, P2- U24) (Pair 12, overall, P1-U23), especially for people who have eyesight problems and wear glasses (Pair 11, D1, P2-VR) (Pair 8, D1, P2-VR) (Pair 6, D2, P1-VR).

6.4.5 Social Interaction and Player Behaviour in Game

Figure 6.13 shows the examples of players’ behaviour and social interactions while playing with the exhibit in this study.



Virtual celebrate (Pair 11, D2, U22)

Calling her partner to come to look at the mine (Pair 10, D2, U19)

they dance together to celebrate their win (Pair 6, D2, U11)

Discussion to find the answer, quiz engage play to have a conversation (Pair 4, D2, U07)

The player warns their partner don’t go inside the furnace (Pair 3, D2, U05)

The player hugs their partner to encouragement (Pair 2, D2, U03)

The player waves her hand to greeting partner (Pair 5, D2, U09)

The player points to the mine to explain partner her thought (Pair 10, D2, U19)

The player greeting partner who plays on a PC, her partner can not react, and only use voice to communicate (Pair 10, D3, U19)

The player uses a PC to interact with his partner (Pair 11, D3, U22)

The player uses a PC to grab coal help her partner (Pair 6, D3, U11)

Pair of players in the physical world do hi-five (Pair 11, D2, U21 and U22).

Figure 6.13 The example of players' behaviour and social interactions during play game.

6.5 Discussion

This experiment aims to investigate problems with and possible solutions to providing social interactions between visitors during play with VR in interactive exhibits. The experiment explores multi-player connection design, the symmetric connection between VR and VR (D2), and the asymmetric player connection between PC and VR (D3). The experiment examines whether or not the designs provide the same experience, or what factors make a difference, especially with respect to design features that affect social interaction between players. The experiment also compares the advantages and disadvantages of single-player (D1) and multi-player (D2, D3). The experiment found a difference in user experience between the three design cases with respect to the sense of presence, sense of co-presence, sense of social presence in the VE, engagement with the exhibit, and knowledge exchange while playing in the exhibit. The experiment found that symmetric player connection between VR and VR differed significantly from user experience in the asymmetric player connection in between PC and VR. The VR and VR connection is better than the PC and VR connection in the sense of presence, co-presence, social presence, and engagement. Only knowledge exchange was the same in both modes of user experience. The experiment also revealed that multi-player differed significantly in user experience from single player, where multi-player engaged players while playing the exhibit more so than single player and provided a chance for players to exchange knowledge.

The experiment also found issues in designing social interaction features from the interview. The design features that best helped players understand and interact with their partner in the VE included a virtual body (VB), facial expression, eye contact, gesture, and voice communication. The experiment found that some design features for social interaction were important, and some were not important in designing social interactions for a science exhibit. The following will explain and discuss these results.

6.5.1 Multi-player Symmetric Design VR and VR Provided Better Social Interaction Experience than Multi-player Asymmetric Design with a PC and VR.

The experiment revealed that the symmetric VR connection offered improved social interactions relative to cooperative VR and PC asymmetric connection. The first factors to discuss in explaining improved social interactions in the symmetric VR connection is the head mounted display (HMD) embodied VR or VR with VB to represent players in the VE. This was important as it allowed players to naturally interact with the VE and with their partner using their whole body [166, 200]. The synchronization of virtual hands and players hands increased engagement and lead to improved interaction with the environment and partner, for example, this made it possible for players give a hi-five when they choose the correct answer in the quiz game, or wave their hands to greet their partner. This offered a similarity with face to face communication in real life [200]. Second, a symmetric VR connection provided more degrees of freedom (DOF). The 6 DOF of HMD engaged players to move around the VE allowed them to more easily interact with their partner.

In contrast, the asymmetric VR and PC connection decreased the social interaction between players because of the limitations experienced by the player using the PC. The static hands of VB degraded player interactions with their partner, despite use of the mouse and keyboard, as this offered a less unnatural interaction. The virtual celebration and social bodily interactions were not possible with the asymmetric connection. Another point regarding the use of mouse and keyboard is that player found it difficult to turn around which affected for players' ability to move their VB into a face-to-face position with their partner. However, both symmetric VR connection and asymmetric VR and PC connection were equally beneficial regarding the use of voice for communication.

6.5.2 The Asymmetric Multiplayer Connection is not the Best Way to Connect Players to Play Together, but It can be an Alternative Way to Connect Players.

Asymmetric VR and PC connection shows a significant decrease four factors: presence, co-presence, social presence, and engagement, when compared to the symmetric VR and VR connection. Nonetheless, players wear able to exchange knowledge and communicate with other players. The use of a PC as an alternative way to connect players provides a social interaction opportunity that is better than no communication channel for several reasons. It offers an alternative way for players who are sensitive to motion sickness using VR. It makes content in VR appear to visitors in the vicinity of the VR exhibit, enabling them to participate in the conversation. Reading text on the PC screen is clearer than in VR for players who have vision problems. However, design interaction via PC or VR should keep features that allow non-HMD users to interact with HMD users. The design should balance the trade-off between the quality of the immersive experience and the opportunity to induce social interaction between other visitors of a VR exhibit.

6.5.3 Multi-player provides a better user experience than a single player.

The social aspect is an essential feature for museum exhibits and recommend by many researcher [165]. This is exactly what was found in the experiment, multiplayer connections offer better experience than the single player VR exhibit, though the feeling of presence or immersive was not significantly different. First, the experiment found having a partner in the VE can reduce loneliness in the VE by allowing players to discuss with their partners. Second, social interaction between players encourages players to play exhibits together, for example, they celebrate when they achieve something in game, or help each other to complete a mission; things a single player is unable to do. Third, multi-player allows players to communicate and exchange knowledge with their partners during interactions within the exhibit. In a situation where players don't know how to solve the problem in the game, their partner can help or tell the player what to do. Therefore, result from this study recommend a multiplayer VR exhibit rather than a single player VR exhibit.

6.5.4 Voice and Pointer are Important Features for Creating Social Interactions for VR Exhibits.

Many researchers have studied the impact of a realistic VB [108] [230] and have found that non-realistic VB has an effect on social interaction [115]. The realistic VB design is intended to ensure the players feel more immersion and avatar ownership. However, the results from this experiment suggests that the facial expression and realistic features of the avatar are not critical for a social interaction that allows players to understand their partners during play with exhibits, especially when the focus is on the mission rather than face-to-face discussion in the VE. The study found that the most significant features are having VB, voice chat, and use of a laser pointer.

Humans communication is both verbal and nonverbal. Nonverbal involves interpreting the message of body language. For instance, facial expressions shows human emotion, eye gaze is a cue indicating the direction of an object or person that the speaker is looking at [61] and using the hand and index finger to point emphasizes the target object in conversation. However, limitations of VB design mean a player is unable to point particularly to a target object, specifically one far away from the player, so the use of a laser pointer enhances the ability of VB to indicate direction.

Indeed, voice is the main feature that players use to communicate. The laser pointer makes the object of the conversation clearer and more precise. Facial expression is unsignificant for communication in this experiment, perhaps because of the specific activities designed for this exhibit. Participants reported that they focused on task rather than face-to-face conversation, because of their position standing side by side, not face-to-face with their partner most of the time during the mission in the exhibit. An avatar's hands are quite important for interacting with partners in the VE and permit more engaged play with the exhibit, but are not significant for understanding message in conversation.

However, the default features of VB might produce positive or negative feelings when the player sees their partner's avatar's face. A participant mentioned that he looked at his partner and saw his partner smile, and it meant she felt good; she was ok. Fischer and Herbert found different responses on type of appearance face expression and emotion [60]. Smile trend to convey an expression of happiness and induce the creation of a social bound [149]. This experiment did not investigate this factor, but the character of avatar face used in this experiment did show happiness or enjoyment. In study of Roth et al. [178], players perceived eye contact increased sense of social presence. Therefore, the default avatar' face might have an effect on player feeling.

6.5.5 Game Style Design Feature for Learning and Social Interaction in VE

Each game design style has different characters and provides different ways players obtain knowledge from the game, while offering different user experiences in terms of social interaction and communication between players. The results from the experiment suggest that in quiz and complete a mission game styles, players tended to have more conversation and discussion than in exploration.

The quiz game style challenges players to find the correct answer. Sometimes they learn from choosing the incorrect answer, but some players did not enjoy answering the question because it is like taking an exam. The quiz game style in this experiment intends for players to find a particular part of the steam engine. The question gives a cue to the player by explaining how the part in question is connected to the other parts as well as its function. When the player plays this game first, they find the parts on the steam engine mentioned in the question and then discuss their thoughts with a friend. This game mechanism induces a conversation and players learn the parts of the steam engine and their functions at the same time. The feedback, whether an answer is correct or incorrect, helps players to learn. The quiz also produces more interaction between players. The experiment often found players celebrate their achievement together when they answer the question correctly, such as giving a hi-five or sounding out “Yay”.

The complete a mission is another game style that produces more conversation among players, but the topic of conversation is different from the quiz. Players often talk about how to solve the problem in the complete a mission game style. They talk about their task to help each other to achieve the mission. They discuss how to divide tasks and how to work together. They discuss the situation experienced during the mission, how to succeed, and what solutions are options at a given moment. Complete a mission in a limited time is quite challenging. The situation when players play VR and VR together is quite realistic and involves emotions. Sometimes players reported feeling nervous and emotional while talking with their partner when they nearly failed the mission, because they wanted to win. When a mission was failed, players felt depressed, especially when a man-woman couple played together.

In terms of learning from completing the mission, the players said that completing a mission evaluated their full understanding of the steam engine and how it works. If they did not understand how the steam engine worked, they could not operate the valve and make the steam engine pump water from the mine. Another way players learned to operate the steam engine was from trial and error. Players often celebrated when they won the game and reported feeling good, experiencing happy emotions, and acting out with hi-fives and dancing with the music in the game.

On the other hand, the exploration game style and explanation game style produced less conversation and interaction between players. The exploration game style provided the player time to explore the content and allowed them to learn about every part of the engine. If the design provided more information about the function of each part of the engine, players would be able to better understand the steam engine. The explanation game style produced less conversation and less social interaction between players, but it was most effective at conveying useful information to the players. Players understood how the engine worked from the explanation, where players listened to the animation without conversation. Figure 6.14 summarizes the relation of game style and social interaction level, showing the levels of player interact with system and between partners.

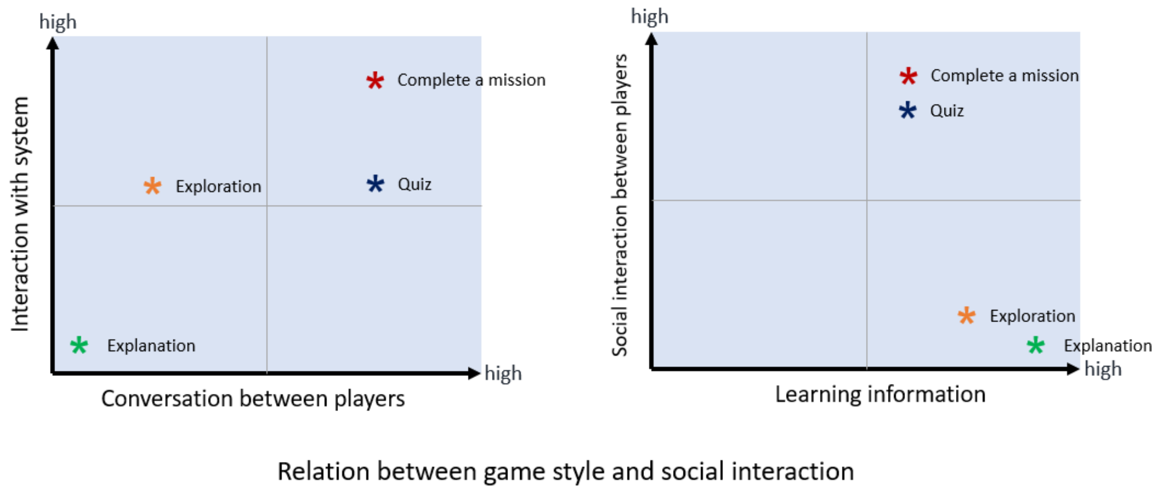


Figure 6.14 The relation between game style and social interaction, compares between exploration, quiz, explanation, and complete a mission game styles.

6.6 Conclusion

The experiment was intended to find a way to provide social interaction between visitors when using VR exhibits. The experiment used three different player connection design cases to investigate user experience and social interaction in the VE. The three design cases included single player (D1), multi-player with a symmetric connection between VR and VR (D2), and multiplayer with an asymmetric connection between PC and VR (D3). The experiment used a game designed by the researcher to teach how a steam engine works. The game had four game styles: exploration, quiz, explanation, and complete a mission. The experiment used a within-subject design by recruiting pairs of players to play the game. 12 pairs of participants joined the experiment. The experiment was conducted during the Covid-19 pandemic, so each participant was placed in a different room and used Zoom to communicate with each other. Each pair had a chance to play all three design cases in equally random order.

The experiment used both quantitative and qualitative research methods. For the quantitative component of this study, the experiment measured user experience based on five factors: presence, copresence, social presence, engagement, and knowledge exchange. The self-report questionnaire was designed using five Likert scales (strongly disagree to strongly agree, 0 and 4). The qualitative component used a semi-structured interview after a pair of participants finished playing a game of each design case, and again after they completed playing with all three design cases.

The statistical results show significant differences in user experience between D1, D2, and D3. A significant difference was found between D2 symmetric multi-player connection (VR and VR) and D3 asymmetric multi-player connection (PC and VR) over four factors: factor 1- sense of presence, factor 2 - sense of copresence, factor 3 - sense of social presence, factor 4 - engagement. It did not show a significant difference in factor 5 - knowledge exchange. D2 provided a higher quality of user experience than D3 in terms of social interaction features in the VE.

The results suggest that using a PC to interact in the VE offers a decreased sense of immersion and less engagement. Players enjoyed playing with the symmetric connection (D2) more than the asymmetric connection (D3). Comparing user experience in D3 between the player who plays PC and the player who plays VR, the experiment found that the PC received a lower score than VR. The lowest scores include item 5- perceive my body, item 2 - high degree of freedom, item 3- feeling that visual aspect involved me, and item 1- sense of being there. This explains why D3 (PC and VR) decreased the quality of the user experience relative to D2 (VR and VR). While using a PC, players were unable use their hands and their body to interact with the player using VR, which decreased social interaction between the players, and decreased enjoyment and engagement.

Virtual body (VB) is important for players to interact with the VE and with their partner, especially using VR. This experiment found VB is less important when playing alone and playing a game on PC when the game is designed with first person view. The features of VB that are most significant to permit communication in the VR exhibit are voice and pointer. Players mainly use voice to communicate their message and use the pointer to emphasize objects or to augment spoken communication by indicating direction. Other features of VB help to increase enjoyment experienced by players. For instance, VB hands allow players to interact socially with their partners, such as waving hands to greet partners and giving a hi-five to celebrate an achievement in the game. Facial expressions like eye contact are less important when players focus on tasks in the game, especially as the layout design led players to stand side by side facing the main object they needed to operate in the game. The features of VB on PC do not support players to have gestures for social interaction.

The game style is a mechanism that induces social interaction between players. This study found that players have more conversation and social interaction when playing the quiz game and completing a mission than in exploration and explanation. The quiz challenges players to find the right answer, and the ‘complete a mission’ game style challenges players to achieve the mission. The conversation and social interaction between players in quiz and ‘complete a mission’ differ. The mission-based game involves more player emotion than the quiz. The four game styles provide learning content to players in different ways, and players also get knowledge from each game style in a different way.

Finally, it is important when designing social interactions between visitors for a VR exhibit to consider what the designer wants visitors to get from the exhibit. Choosing between design symmetric and asymmetric multiplayer connections (D2 and D3, respectively) affects user experience. The main features that help players to communicate with their partners are voice and pointer, so the designer does not need to spend time designing other aspects of VB, like facial expression. However, the VB hand is an important feature that allows players to interact with their partner in VE and increase enjoyment.

Chapter 7 Content design of an exhibit in the virtual environment

7.1 Introduction

Using VR exhibits in museums offers variety in the design. The design could simulate a virtual museum hall or one virtual exhibit. Many museums display their gallery in the form of virtual exhibits, which often include flat screens displayed in the virtual environment (VE), a virtual 2D image in a virtual 3D environment. There is doubt about this type of 2D design, as it might decrease ability of VR to deliver an immersive experience to users [196] . Another unique feature of VR is that embodiment allows players to interact with the VE by hand and body [99]. The design content for a VR exhibit affects how visitors learn and remember. A VR exhibit can provide an active or passive learning style to visitors. Active style allow learner to interact with the exhibit, and passive style does not offer visitors to interact with the exhibit. Many researchers believe immersive media supports players in learning and memorising the story more than non-immersive media [21, 110]. So, the 2D view design might affect user learning and memory from the exhibit.

This study addresses research aim five by investigating the effect on the user experience of design content in a VE, comparing 2D view design and 3D view. This study simulated two design cases: the 2D view is a flat-screen display in the VE, and the 3D view is the whole VE experience. User learning, memory, immersion, and emotion are measured.

This chapter starts with section 7.2 outlining the goals of this study and section 7.3 explains this study's design, including system design, content and narrative story, system implementation, participants, measurement, and procedure. Next, section 7.4 reports both quantitative and qualitative results found from this study and section 7.5 discusses the interpretation of what this experiment found, along with a suggestion for designing content for a VR exhibit. Finally, section 7.6, will summarise the findings of this study.

7.2 Study goals

This study investigates how players' learning and memory are affected by perception (view) and are related to embodied action in the VE.

Research question

The research question for this experiment is: how does 3D versus 2D view impact user experience in term of learning and memory in a VE?

Hypotheses

The experiment has two hypotheses it intends to investigate:

H1: The 3D view offers better efficiency for players learning content in the VE than the 2D view. Efficiency refers to the exhibit offering players to gain knowledge after experience with the exhibit.

H2: The 3D view offers better efficiency for players remembering a story in the VE than the 2D view. Efficiency refers to the exhibit support player remembering the exhibit's story and their experience, able to retain and recall it after they experience the exhibit.

Variables

The variables for this study are:

Independent variable: perception in the VE: the 2D view is the flat screen display in the VE, and the 3D view is the whole virtual environment.

Dependent variables: learning, memory, immersion, and emotion.

Control variables: the topic of VR exhibit content, the narrative content, the first-person perspective game design, boundary degree of movement and direction, action and interaction with the game design.

7.3 Study Design

7.3.1 System Design

This experiment uses two cases of player perspective in a VE: 2D view and 3D view. The two design cases provide a different view of accessing and manipulating the VE content. Figure 7.1 shows example scenes of the 2D view and 3D view. Details of the 2D view and the 3D view are as follows:

2D view design: the player wears an VR HMD (Oculus Quest 1) to experience the VE. The whole VE simulates an exhibition hall where the player can move around. An interactive flat-screen is displayed on the middle wall in the exhibition hall. The player stands in front of and interacts with the game via a large flat screen. The player interacts with the game's objects by using the controller to point the laser beam on top of an object and clicking to select the object. The player controls movement in the game by pressing the Thumbsticks button on the right-hand controller to move left, right, forward, and backward. The player rotates the game's view by pressing and holding the Trigger button and simultaneously panning the right-hand controller- left to right, or right to left, or up to down, or down to up. Figure 7.2 shows the controller mapping, and Figure 7.3 shows an example of how to pan view in the 2D design case.

3D view design: the player wears an VR HMD (Oculus Quest 1) to experience the VE. The player uses the controller to select an object by pointing the laser beam on top of the object and then pressing the Trigger button to select the object. The player controls the movement in the game by pressing Thumbsticks to move left, right, forward, and backward. By moving their head, the player can explore the scene.

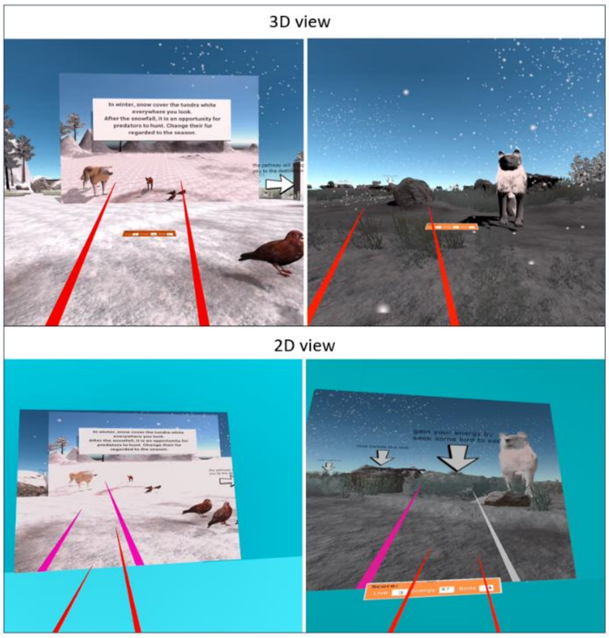


Figure 7.1 Example scenes of the example of 2D view and 3D view.

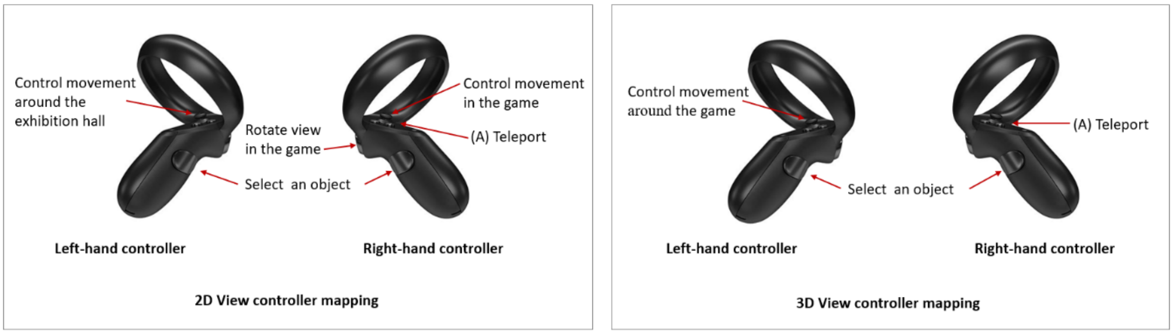


Figure 7.2 Controller mapping between 2D view and 3D view.

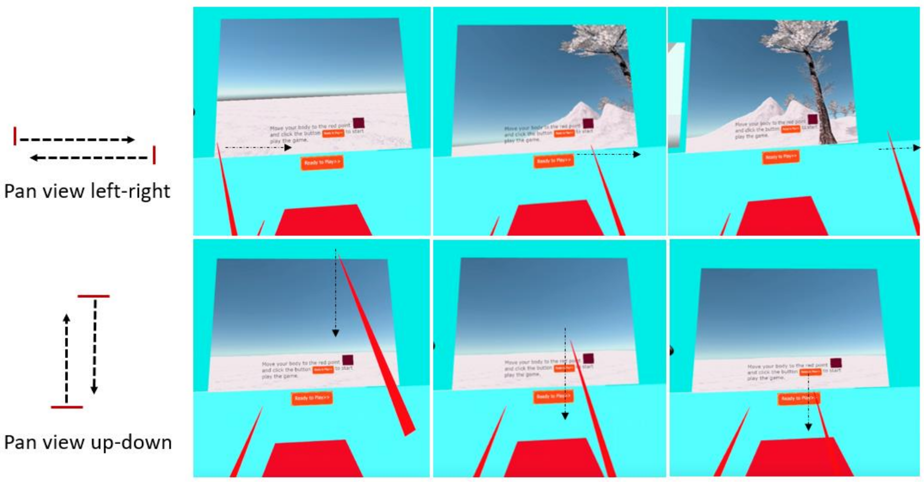


Figure 7.3 Example of pan view in 2D view design case.

7.3.2 Content and Narrative Story

The interactive exhibit aims for players to learn about camouflage, its purpose, and how animals adapt themselves to survive. The exhibit’s design applies a mixed style between storytelling and game-based learning. The players will play the role of a fox trying to survive in the Tundra environment for over one year. The VE season will change from winter to summer and back to winter at the end of the story. During the season change the fur of animals in the game changes according to each season. The player has two activities to do; seek Ptarmigan birds to gain energy and hide from wolves to avoid being eaten. The narrative of the story is adapted from an exhibit about camouflage displayed in the RAMA 9 museum. Figure 7.4 shows examples of the scenes in the VE. The game sets the mission and tasks for the player to do as follows:

- you must survive until the next winter.
- seek and catch the Ptarmigan birds so that you can gain your energy.
- if you run out of energy, you will lose one life.
- one bird is equal to one point.
- if you are hunted by the wolves, you will lose one life.
- you can survive by running away from wolves or hiding in the “hideout areas”: bushes, snow hills, mounds, and snow caves.

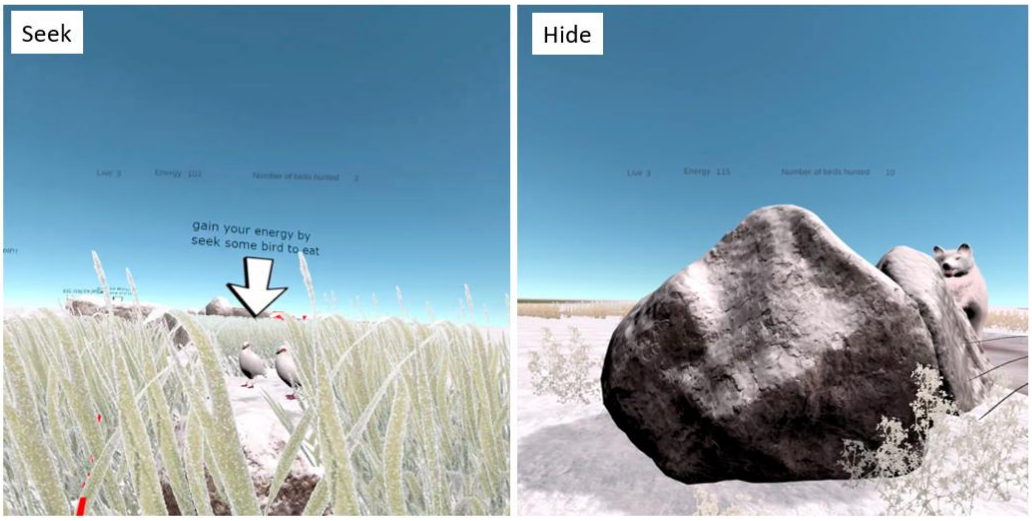


Figure 7.4 Example scene of two activities in the game; seek birds and hide from wolves.

7.3.3 System Implements

The Unity engine is the main software used to develop the game. Blender is the main software used to create 3D models for the game. For the 3D model of Ptarmigan and fox, the researcher received help from other people to create the master model and simple rigs. After that, the researcher modified and generated characters for the bird and fox. For the wolf model, the researcher bought an asset from the Unity Asset store and modified its behaviour. Finally, all the animals' avatar animations were generated in Unity. The terrain design used components from the standard Unity assets and some bought components from the Unity Asset store. The 2D view design used a mirror technique. The player takes action, and the actual action happens with the fox avatar model interacting with the object in the Turda environment. The player controls the fox's movement, and the pointer's movement in the interactive wall is relative to the player's hand movement. The situation was captured and displayed on a mirror for the real player who was playing the game in the exhibition hall and controlling the action of the fox avatar model. Figure 7.5 show the overall 2D view system design.

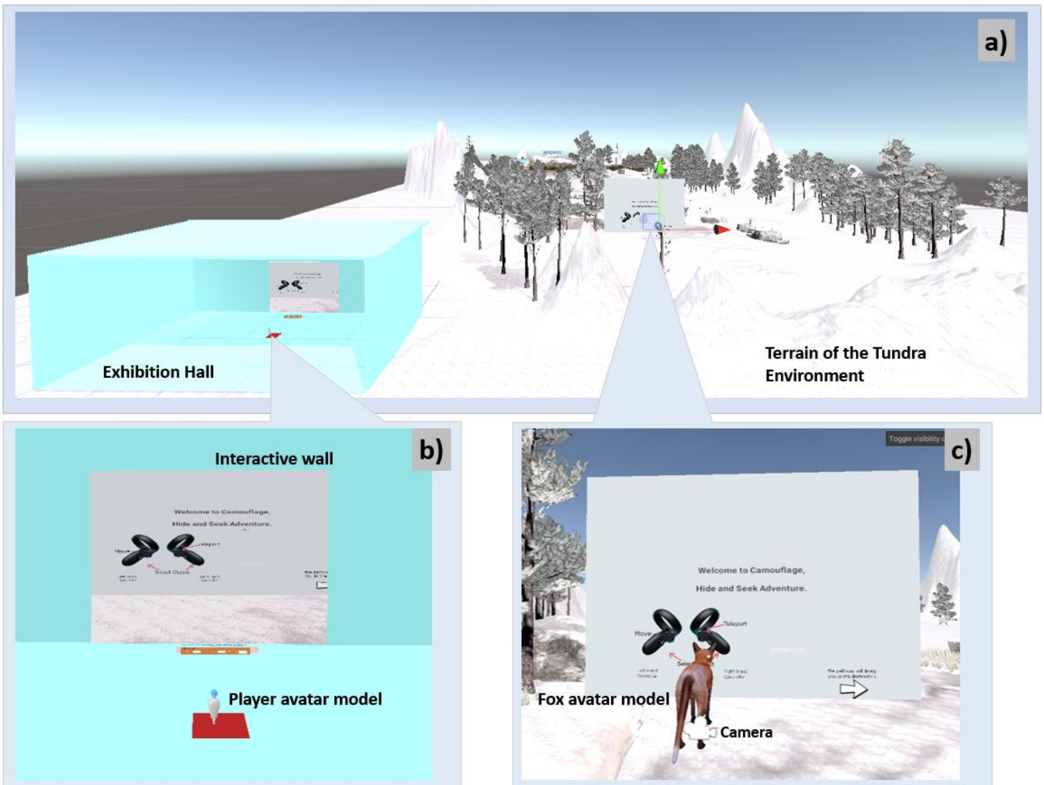


Figure 7.5 System design technique for 2D view. a) the scene environment consists of the Tundra environment and exhibition hall and the interactive wall display inside the hall. b) show the component of the 2D view system. The player stands in front of the interactive wall and interacts with the game via the interactive wall. The interactive wall displays the environment from the fox's camera, which walks in the Tundra environment. The player controls the action of the fox. c) the fox avatar model in the Tundra environment, which is controlled by the player, the view of the fox's camera is captured and displayed on the interactive wall.

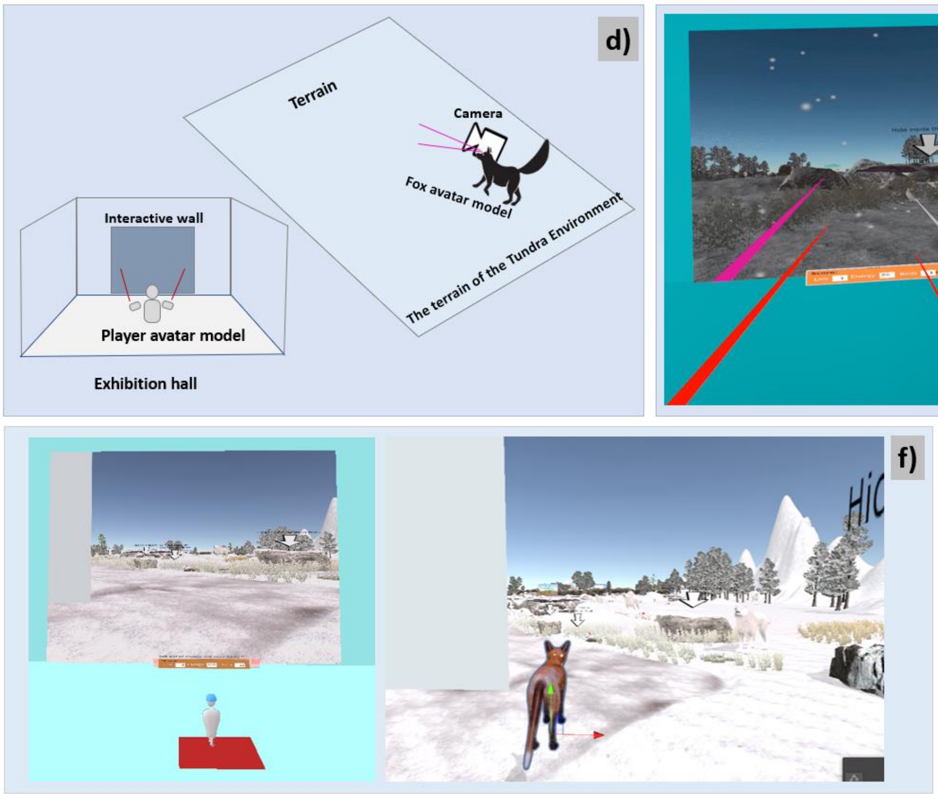


Figure 7.6 System design technique for 2D view (cont.). d) show the main component of the 2D view system. e) show the captured image from the game in the headset, which shows the pointers. The red one control by the player, and the pink one is the fox's pointer which moves related to the player's pointer. It turns white when it hits an interactable object in the scene. F) show an example of a captured image of the interactive wall from the game, the display on the interactive wall changes related to the fox's view.

7.3.4 Participants

This experiment uses a between-group study to prevent people from learning the same content, which affects their learning and memory. The study expected to recruit 20 participants per group via an invitation email. The email was circulated to students in the School of Computing Science and the postgraduate community. The researcher also created an advertisement published on the notice board inside the College of Science and Engineering building. However, in the actual situation, the experiment was run during the Covid-19 pandemic, and only 16 people per group could participate. Each participant was given a £6 Amazon gift voucher for compensation.

7.3.4.1 Participant Demographics

Thirty-two participants joined the study, 16 for the 2D view and 16 for the 3D view, though only 29 participants were able to complete all the processes of the experiment (pre-test, experience with VR exhibit, post-test, two weeks post-test). Therefore, the following results are reported from 14 participants for the 2D view and 15 participants for the 3D view.

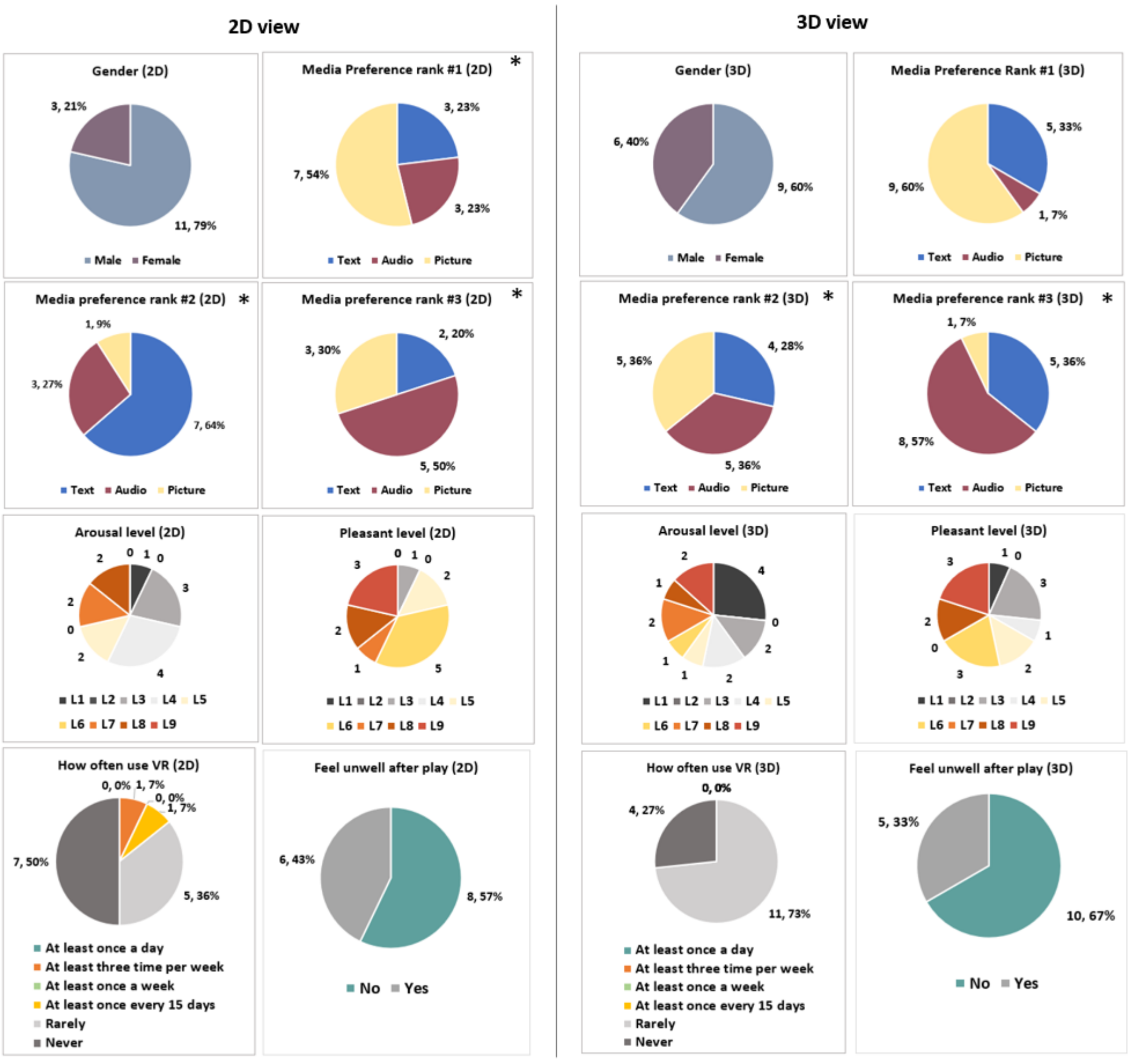


Figure 7.7 Participants' background information, 2D view and 3D view.

7.3.5 Measurement

This experiment uses qualitative and quantitative data to answer the research question. The experiment measures four factors: knowledge, memory, immersion, and emotion. The four factors are:

1) Knowledge assessment: the experiment intends to investigate the effect of the 2D view and the 3D view in the VE on learning. Various ways to assess the efficiency of game-based learning are mentioned in the study of Gris and Bengtson [76]. This study used a pre-test and post-test created by the researcher for this study to evaluate participants' knowledge gained from the VR exhibit. The questions in the pre-test and post-test are the same, but the post-test's questions sequence is changed to minimize effect of response to earlier question influent to subsequence question. The generic learning outcome (GLO), a measurement outcome of an exhibit mentioned in the study of tom Dieck et al. [212], is defined before creating the VR exhibit. The questions in the test are generated to reflect the learning outcome. The score criteria for the correct answer are defined before running the experiment. However, the answers to the short open question are assessed based on content as opposed to the exact language of the defined answer [81].

Learning outcome

What is the intent they do? Play a game and explore the natural phenomena of camouflage.
How is the intent they feel? Playful, sympathy.
What are its values? Positive attitude toward animal life and nature.
What is knowledge or understanding? 1) understand the purpose of camouflage, 2) understand how animals adapt themselves to survive in nature, and 3) understand the role of animals in the environment.
What is the skill they will develop? the exhibit does not has main aim to develop player's skill, however, the exhibit offer a player to make a decision in the critical situation.

2) Memory assessment: memory assessment here refers to both episodic memory and long-term memory. Episodic memory relates to how much people can remember about the story or events that happened to them during their experience with the exhibit [145]. Long-term memory refers to how participants recall their experience in the 2D view and the 3D view. The experiment used memory test questions created by the researcher to evaluate memory immediately after having the experience and then again two weeks later. Different modalities of media affect long-term memory differently [142] so the memory test created aims to examine cover all modalities of learning media: visual, auditory, and embodiment. The score criteria or the correct answer are defined before running the experiment, but the answers are assessed based on content as opposed to the exact language of the defined answer.

3) Immersion assessment: one of the dominant features of VR is delivering an immersive experience to players. Prior research suggests that learning media which produces more immersion will increase the ability of learners to remember media. One study, for example, study found that HMD VR better supported people's ability to memorise objects in VE than desktop display [110]. On the other hand, some research found that a sense of immersion is not directly related to memory, but it might depend on the features of media design for VR [201]. The use of a 2D view might decrease immersion compared to the 3D view, which might affect memory, so this experiment will assess the immersion between the 2D view and the 3D views. The experiment measures immersion by through subjective measurement, if the system has higher immersion, it will provide a player with a sense of presence in VE, which believe a sense of presence is the outcome of immersion. The items created are based on the component to create illusion of Presence that proposed by Jerald [98]. The component comprises four cores: the illusion of being in a stable spatial place, the illusion of self-embodiment, the illusion of physical interaction, and the illusion of social communication. This experiment uses only three components, except for the illusion of social communication, which is not investigated in this study. The items composed as follow:

- I had a sense of being there in the exhibit rather than I saw the exhibit. (a stable spatial place)
- I have a high degree of freedom to move around inside the virtual exhibit. (a stable spatial place)
- I feel the visual aspect of the virtual exhibit involves me. (a stable spatial place)
- I feel the audio aspect of the virtual exhibit involves me. (a stable spatial place)
- I perceive my body in the virtual exhibit environment. (self-embodiment)
- I naturally interact with the object in the virtual exhibit. (physical interaction)

4) Emotion assessment: learners' emotion affects how they learn and memorise things. The learner remembers content associated with positive and negative arousal better than neutral non-arousal content [39]. Some researchers found that negative emotion reduces explicit memory [213]. Another piece of evidence found that the Goose Bumps: The Science of Fear exhibition delivered an emotional experience to visitors, especially an emotional arousal experience, which induces longer-lasting memories than non emotional arousal experience [57]. A study discussed in [57] examined an exhibit that allows visitors to feel fear in a safe environment. After three or four months after the visitors have visited the exhibition, visitors can remember what they saw, did, and felt more so than visitors visiting normal exhibitions. The storytelling design for the present study assumes that the 3D view is more immersive [196] might relates to self-embodiment in the VE of the player and make the player feel more fear of the wolf's attack than the 2D view, and that this will affect the player memory and learning. So this study will measure the player's emotion on two factors: 1) arousal (alertness) and valence (pleasure), assessed using Affect Grid [179]. It is a single-item scale of pleasure and arousal. 2) The positive affect and negative affect scale (PANAS) assessed using 20 items on a 5-point scale. The Affect Grid measures the player's emotions before and after playing with the exhibit, while PANAS [40] is used only after the player plays the exhibit.

In addition, the questionnaire includes a question to investigate stimulated motion sickness in participants to investigate whether sickness has effect participants to answer the questionnaire. The experiment did not assess learning preference style because it has been found that learning preference does not affect learning and memory and there is no effective test to assess learning style for evaluated learning media [155].

7.3.6 Procedure

All equipment is set up in one room and initialised before each participant joins the study. Figure 7.6 shows the room used for running the study. The study was conducted during the Covid pandemic, but the restriction rule for close contact with other people was relaxed. The experimenter and a participant stayed in the same room. The steps of the experiment are described as follows. 1) The experimenter explains the detail of the study to the participant, and the participant signs a consent form. 2) The participant completes a questionnaire about personal background information, does the Affect Grid to assess the participant's emotion before playing the exhibit, and does the pre-test knowledge assessment. 3) The participant wears a VR HMD and experiences the exhibit. The experimenter observes the participant's behaviour while they play through the exhibit. 4) After the participant finishes playing the exhibit, they are asked to do the post-test, memory test, self-report questionnaire of immersion and emotion (Affect Grid, PANAS), and a question about motion sickness. And after the participant completes the test, they were interviewed about their experience with the exhibit, and asked to tell the story that they have the experienced. 5) Two weeks following the participant's experience with the VR exhibit, the researcher conducts a meeting online with the participant via Zoom. The participant is asked to complete a post-test and repeat the memory test via an online form, followed by a short interview about their experience with the VR exhibit.

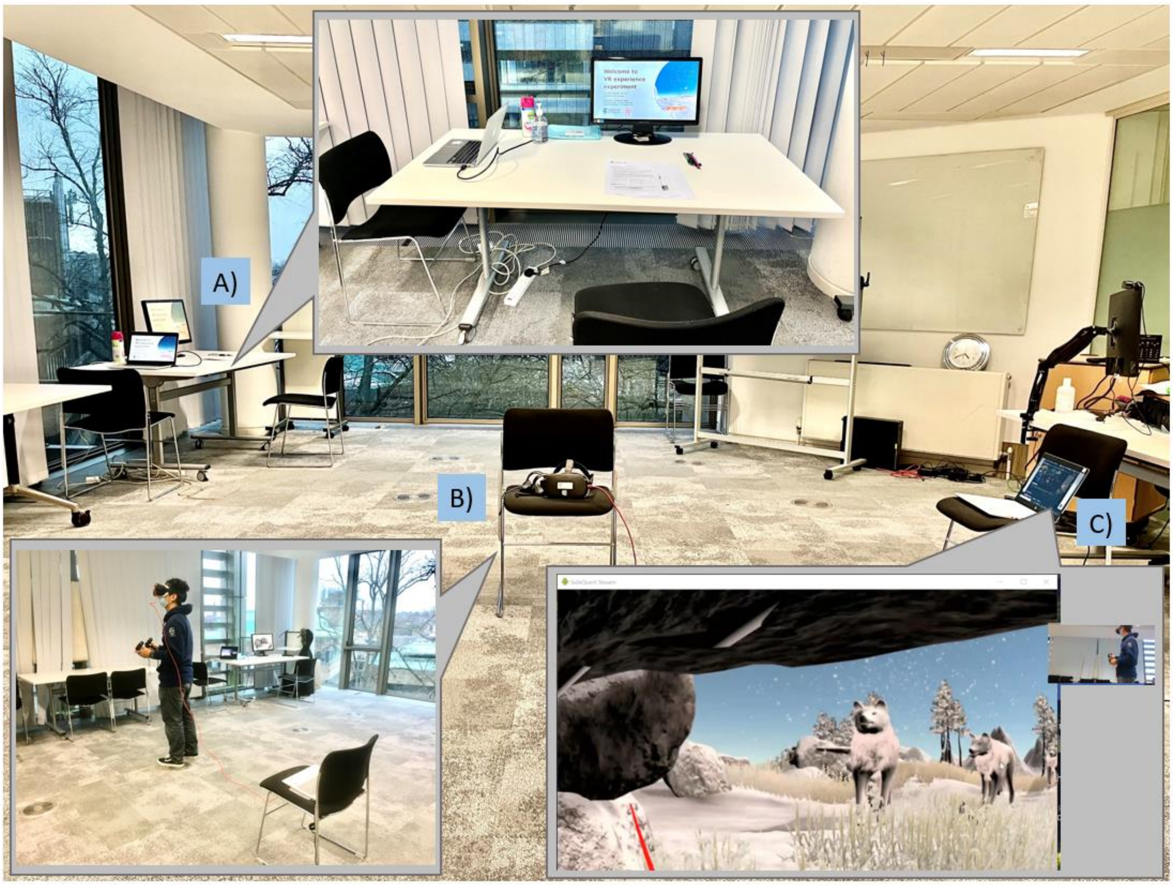


Figure 7.8 The room for running the experiment, with all equipment ready and initialised for each participant. A) a table setup for the experimenter to the explain task, interview the participant, and for the participant to complete the test. The pictures in the test are shown on screen while the participant complete the test. B) A participant wears the HMD and plays with the exhibit within the limited physical area. C) The content in HMD was streamed and displayed on a laptop screen to allow the experimenter to observe the participant's behaviour during play the exhibit.

7.4 Results

7.4.1 General Results

7.4.1.1 Learning

The results show participants gained knowledge after having experienced either the 2D view or the 3D view. Changes in scores between the pre-test and post-test are used to the evaluate potential of learning media, as discussed in study of Delucchi [43], and study of Gliner and Morgan [70]. Table 7.1 show the learning scores, allowing comparison between the 2D view and the 3D view. Test results two weeks after having the show a decrease in test score for the 2D view by 0.286 from post-test. The results show a significant difference between the pre-test and post-test on both the 2D view and the 3D view according to the nonparametric Wilcoxon signed-rank test with the 2D view at p = 0.01, Z =2.561 and the 3D view at p = 0.001, Z = 3.413. The results did not show a significantly difference between the post-test and after two weeks test, with the 2D view at p = 0.132, Z= -1.506 and the 3D view at p = 0.512, Z = 0.655. The nonparametric Mann-Whitney test (α = 0.5) is applied to compare the test between the 2D view and the 3D view, and the results did not show a significant difference between the post-test and after two weeks test, where post-test p = 0.861, Z = -1.75, and the after two weeks test p = 0.229, Z = -1.202. The results differ significantly from the pre-test where pre-test p = 0.048, Z = -1.977.

In summary, the result indicates that the differences between the 2D view and 3D view do not affect to facilitate players to gain knowledge from a VR exhibit. And they do not affect player knowledge retention, as indicated by the results that have no significant difference between the post-test and the after two weeks test. So, both views have the same potential to offer players to gain knowledge.

Table 7.1 Learning score, pre-test, post-test and after two weeks test, the maximum possible score is 4.

View	N	Pre-test		Post-test		after 2 week		dif. pre vs post	dif. post vs after	Significant test (α = 0.05)	
		M	SD	M	SD	M	SD			pre vs post	post vs after
2D view	14	1.843	0.992	2.979	0.828	2.693	0.749	1.136	-0.286	0.010 (Z=2.561)	0.132 (Z=-1.506)
3D view	15	1.247	0.639	2.900	0.848	3.020	0.891	1.653	0.120	0.001 (Z=3.413)	0.512 (Z= 0.655)

7.4.1.2 Memory

The results show that the memory score for the after-two-weeks test slightly decreased from those in the post-experiment memory test, by -0.215 for the 2D view and by -0.230 for the 3D view. Table 7.2 shows the memory score comparison between the 2D view and the 3D view. The results were not significantly different between the memory test after the experiment and after two weeks for both the 2D view and the 3D view. According to the nonparametric Wilcoxon Signed-rank test (α = 0.5) where the 2D view had p = 0.414, Z = -0.816 while the 3D view had p = 0.164, Z = -1.392. The nonparametric Mann-Whitney U test (α = 0.5) is applied to compare the memory test between the 2D view and the 3D view. The results did not show a significant difference between the 2D view and the 3D on both post memory test and after two weeks memory test, where the post-memory test had p = 0.616, Z = -0.502 and the after two weeks memory test had p = 0.948, Z = -0.065.

Table 7.2 Memory scores for post experiment test and the after two weeks test, where the maximum score is 7.

View	N	Memory Post		Memory After 2 week		Memory dif. post vs after	Significant dif. test post vs after (α = 0.05)
		M	SD	M	SD		
2D view	14	5.170	1.229	4.956	1.436	-0.215	0.414 (Z= -0.816)
3D view	15	5.378	1.123	5.147	1.171	-0.230	0.164 (Z= -1.392)

7.4.1.3 Immersion

The statistical results, given in figure 7.7, show the 3D view produces more immersion than the 2D view in all aspects. Furthermore, the non-parametric test Mann-Whitney U is applied to compare immersion between the 2D view and the 3D view, and the results show a significant difference in immersion where p = 0.012, Z = 2.489.

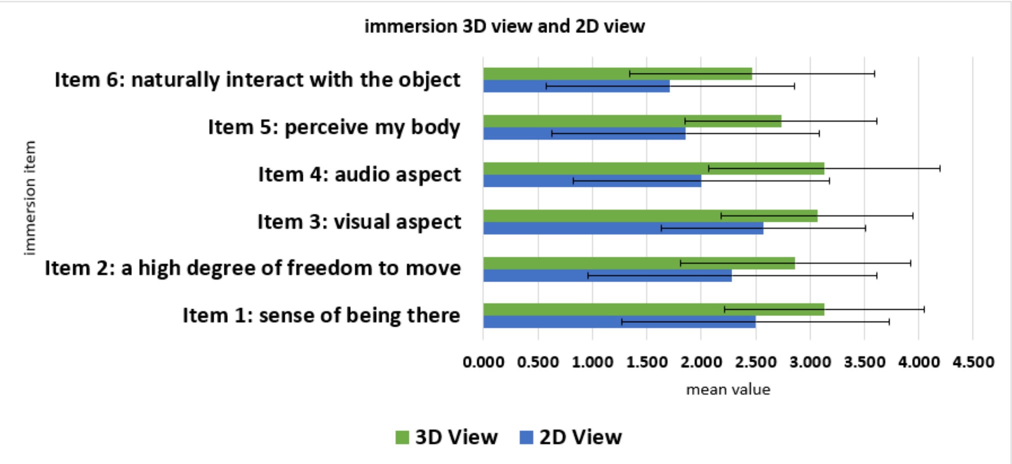


Figure 7.9 Comparison of means of immersion between 2D view and 3D view, with standard deviations shown as error bar.

7.4.1.4 Emotion

The results show the 3D view influences players' emotions more so than the 2D view. The results show players feel more arousal and pleasure on the 3D view than with the 2D view. The results of PANAS show the 3D view received a higher score than the 2D view on almost all emotional affective items, except for guilty, irritable and ashamed. The affective items that received a score higher than 3.00 (moderately level) include interested 3.429 (SD =

0.938), alert 3.357 (SD = 1.151), active 3.5 (SD = 0.519), excited 3.071 (SD = 0.997), and attentive 3.071 (SD=0.829) respectively. Figure 7.8 shows the comparison of mean values for each affective item between the 2D view and the 3D view. The 20 affective items are divided into five factors: negativity, afraid, strong, attention, and aroused [1, pp. 68-70]. The result of the five factors is shown in Figure 7.9 b. The non-parametric test with the Mann-Whitney test (α=0.05) was applied to distinguish different emotion factors between the 2D and 3D views. The results show a significant difference in the factor aroused, where *p*=0.001, Z= -3.1, attention where *p* = 0.023, Z = -2.326, and afraid where *p*=0.037, Z = -2.111.

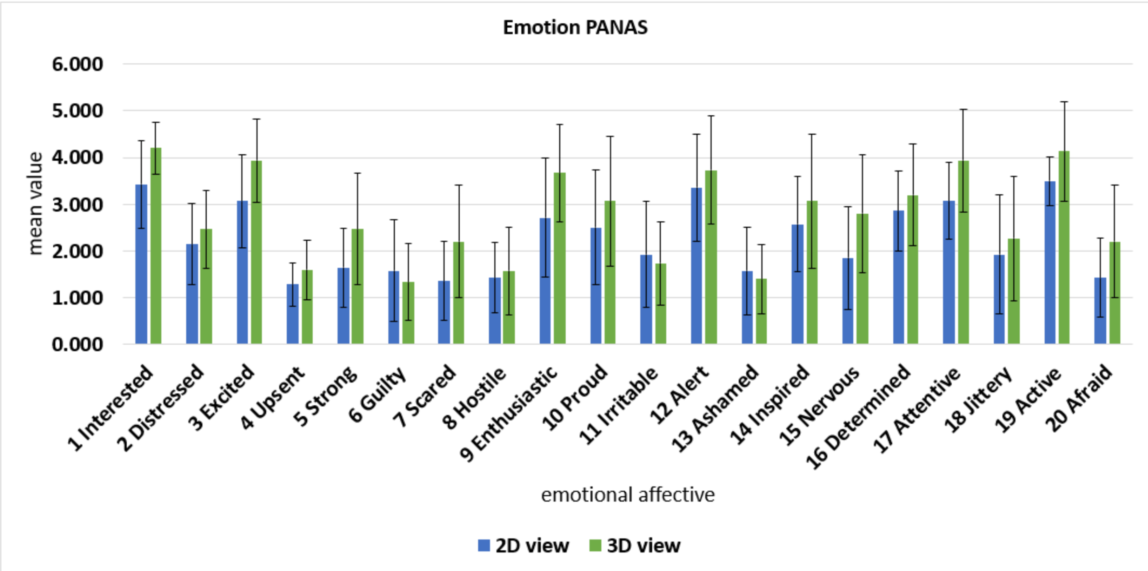


Figure 7.10 Comparison of means of emotional affective in PANAS between 2D view and 3D view. (*hostile 3D view N=14, and the rest items of 3D view N=15)

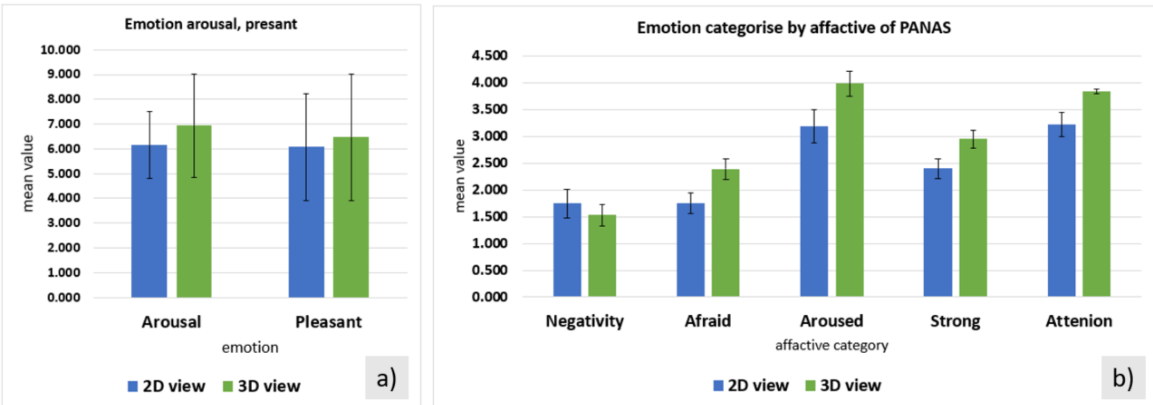


Figure 7.11 Comparison of mean of emotion between 2D view and 3D view a) arousal, pleasant b) emotion factors of PANAS.

7.4.2 The Hypotheses Test

7.4.2.1 Hypothesis 1

: *the 3D view offers better efficiency for players learning content in the VE than the 2D view*.

The non-parametric test Mann-Whitney (α = 0.05) was applied to find the difference in learning between the 2D and 3D views. The results were not significantly different in learning scores of the pre-test, post-test, and after two weeks test, where the pre-test p= 0.051, Z= -1.977, the post-test p = 0.880, Z = -0.175, and after two weeks test p = 0.234, Z= -1.202. Therefore, this hypothesis is rejected. The 2D view and 3D view have the same potential to provide learning to players.

7.4.2.2 Hypothesis 2

: *the 3D view offers better efficiency for players remembering a story in the VE than the 2D view.*

The non-parametric Mann-Whitney test (α = 0.05) was used to find the difference between the 2D view and 3D view on memory. The statistical results were not significantly different between the 2D view and the 3D view on both the after experiment memory test and the after two weeks memory test, where after the experiment p= 0.621, Z = -0.502, and after two weeks p = 0.949, Z = -0.065. This hypothesis is rejected. The 2D view and 3D view have the same potential to support players to remember the story.

In conclusion, the 2D view and the 3D view did not show significant differences in learning and memory. The participants who play the 2D view and the 3D view obtain the same level of knowledge from the VR exhibit and can remember the story at the same level. However, the experiment found that the 2D view and 3D views influence immersion and emotion at different levels. The 3D view offers more immersion and more emotion than the 2D view, and these two factors did not have an effect on learning and memory. This point will be mentioned in the discussion section.

7.4.3 Qualitative Data the Result from the Interview.

A semi-structured interview was conducted after a participant experienced the exhibit and again two weeks after their experience. The interview includes asking each participant to told the exhibit's story that they can remember. Three criteria features of the exhibit are used to indicate how a participant is able to remember the story of the game in the VR exhibit. The three criteria are 1) *sequence*, a player can remember changing seasons in the game (winter, summer, winter); 2) *activity*, a player can remember their activities in the game to seek birds and hide from wolves; 3) *game character*, a player can remember what happens with animals' fur in the story (foxes, wolves, and birds). If the participant did not mention some of the three criteria, the experimenter would ask them to clarify what they cannot remember or what they failed to mention. The researcher read the participant's answer in the post-test and memory test before interviewing the participant for the second time. In case a participant answered a question incorrectly, then an additional question was used to identify the issue. A summary of the questions used in the semi-structured interview is shown in table 7.3.

Table 7.3 The question used in the semi-structured interviews.

Interview Question
Memory test about the story question.
1. Please describe the story that you have the experience with the exhibit (whole story).
General Question after has experience
1. Do you have any problem playing with the exhibit.
2. How do you learn from the exhibit.
3. Do you have any recommendation.
General Question after two weeks had the experience.
1. Which feature of exhibit help you remember the story.
2. Which feature of exhibit help you learn content from exhibit.
3. Do you have any recommendation.
4. How do you feel of the wolves. (feeling about the wolves).

All interview records are automatically transcribed into text files using the Otter.ai program. Then, all the transcript files are corrected for each sentence by the researcher. Next, all edited transcript files are analysed using NVivo software for coding and thematic analysis, as suggested by Bopp et al. [23], Gowler and Iacovides [74], Braun and Clarke [24], Terry and Hayfield [209]. The process includes 1) identifying patterns in data, selecting interest data that relate to the research question, grouping them, and labelling them by defining the scope and meaning. 2) Generate themes by identifying each group of selective data to combine them to define a potentially relevant theme to answer the research question. The final themes are shown in Figure 7.10. Illustrative quotes are labelled with a pattern display participant ID, the view the participant used (2D or 3D), and when the interview is conducted (I= immediately following the experience with the exhibit, P = post experiment two weeks after having the experience with the exhibit). For example (U3D-07, 3D, P) means the quote is from participant ID U3D-07, who played with the 3D view exhibit and the interview was conducted two weeks post experiment.

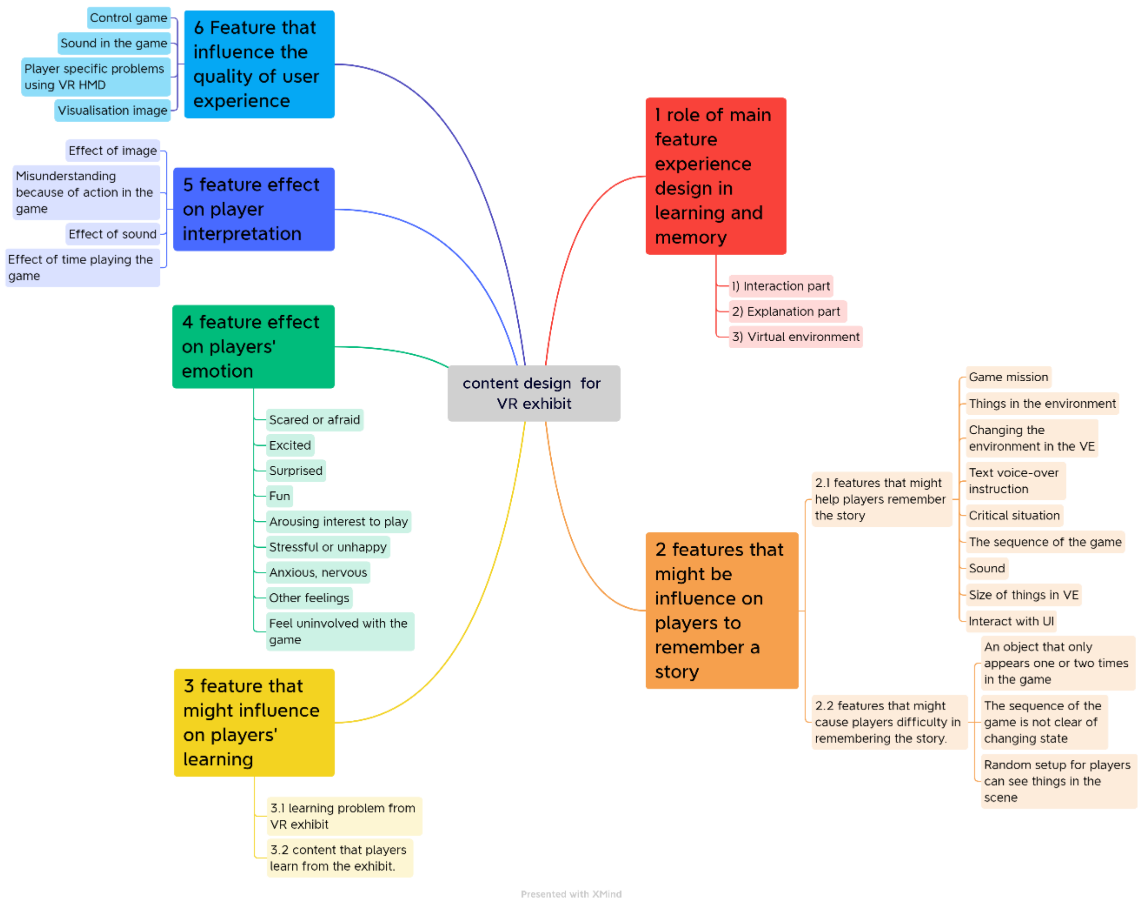


Figure 7.12 The final thematic map representing the six key design features in influencing user experience.

7.4.3.1 Theme 1: Role of Key Feature for Design Experience in Learning and Memory

This theme focuses on how main feature design experiences play different roles in how players learn content from the exhibit and how players remember a story. There are three main features to mention in this theme: the interaction part, the explanation part, and the virtual environment.

1) Interaction part: experiencing interaction with the VE is the most effective feature in helping players remember the story in the VR exhibit. Game mechanics and activities induce players to interact with the VE and game agent (U2D-07, 2D, P), allowing players to have experience by themselves in that situation (U2D-07, 2D, P). A participant said "...the things that stick out are the images of me running along the Tundra and looking for the birds and avoiding the wolf" (U2D-13, 2D, P). Role-playing is one game style that allows players to pretend to be something, such as playing the role of a fox to survive in the environment. It requires players to perform activities like a fox does to live (U2D-09-P, 2D, P) (U3D-04-P). All activities that they do according to the role of the game force players to behave and feel like an actual fox (U3D-07-P, 3D, P) and help them remember each situation they encounter in the story (U3D-06-P, 3D, P).

A gamification technique that applying game mechanics to create experience to players, and the activities designed for the game help players remember the story. Even if an interaction is simple, if it relates to the game's context (story, knowledge, topic content), it makes the interaction with the game more meaningful, and it helps players remember the story. For example, the activities of this game consist of two things, "hide and seek", but the two activities bring players to have their journey of experience (U3D-10, 3D, P) (U3D-02, 3D, P) (U2D-04, 2D, P).

On the other hand, the interaction part is not the most important feature that participants mentioned in learning the content from the exhibit, though it did improve understanding. The game mechanic design helps players learn from their experience by interacting with the environment, especially by using VR to lead players into real-life situations (U2D-04, 2D, P). Sometimes learning through experience provided new perspective. For an instance, the fox has to hide in the cave (U2D-07, 2D, I). Another player mentioned that "… I learn from that what I should do…I think it is a very good thing that if you want to learn something, you should, like, let yourself in that environment." (U3D-07,3D, I). The interaction part provides an experience that gives extra insight knowledge to the players, even though players may have that knowledge before. It gives them a new perspective of knowledge "… it's not learning a fact, but it's more like a gain an experience…when you're actually moving through the environment, and I think that was a cool experience you can't really get otherwise. So that's the best thing that I think I learned from or took away from the exhibit" (U2D-04, 2D, I).

2) Explanation part: the explanation part includes instruction, storytelling, and explaining information. Most of the participants mentioned they learned the contents of the exhibit from this feature. The instruction provides basic background information about the story "…I heard someone tell the story to provide knowledge about Tundra and animals" (U2D-03, 2D, P). It makes it easy for the player to understand the game's situation (U2D-04, 2D, I) and the exhibit's content (U2D-15, 2D, P). The text-over voice explanation supplements information that helps players understand the story (U2D-08, 2D, P) (U2D-T01, 2D, I). The narrator shows information, text, and an image with voice over on the screen (mirror) which helps them learn the content from the exhibit (U2D-10, 2D, P). It provides brief information about how animal survives in the environment (U3D-12, 3D, P).

Players reported that when the mirror reflected the player's avatar body (the fox) in the mirror and showed how the animal's fur changed this also helps them to learn (U2D-T01, 2D, I). Seeing something happen while hearing the narrator explaining it makes the learning content more obvious (U2D-13, 2D, I). The instruction also gave players an idea of what to do and how to play in the game (U3D-02, 3D, I) (U3D-04, 3D, I) (U3D-06, 3D, P) (U3D-11, 3D, P).

3) Virtual environment: the simulated environment helps situate players within the learning content. For example, a participant reported that the VE in the game was correlated with how animals' fur changed according to each season. These changes help the participants learn how animals live in the real Tundra (U3D-09, 3D, P). Furthermore, participants reported that the changing virtual environment helped them better understand the situation and served as a source of learning content (U2D-10, 2D, I) (U2D-11, 2D, I). Therefore, creating the virtual environment relate to the content, will help players understand the relationship between the story and the game's environment.

The VE is the one feature that makes people remember the story. Many participants mentioned that the things they saw in the VE helped them remember the story, especially aspects of the environment that changed. The changing of the 3D objects in the environment makes players feel like the real physical environment changed (U2D-13, 2D, P) (U3D-12, 3D, P). The virtual environment helps players distinguish the differences in the colour of objects and the environment (U2D-13, 2D, P) (U3D-12, 3D, P). However, all design elements of the game include things in VE, and the game interaction mechanism helped participants remember (U3D-15, 3D, P).

7.4.3.2 Theme 2: Features that might be Influence Players to Remember a Story

This theme focuses on how feature design for VR exhibits affects players' memory of a story. The theme is divided into two sub-themes: features that might help players remember the story, and features that might make players have difficulty remembering the story.

1) **Theme 2.1 Features that might help players remember the story**

There are many design features of a VR experience that aim to help players remember the story of an exhibit. From this experiment, players reported various features of the VR exhibit that helped them remember the exhibit's story. They are:

Game mission: the game mission leads players to interact with the environment and agents in the game. For example, a participant said that they could remember because of the game's mission "I had to eat the ptarmigan birds to keep my energy up and avoid being eaten by the wolves, and there was a place I could hide to avoid being eaten from the wolves…" (U3D-T01, 3D, I). Most of the players were able to remember the main activity in the game, for example participants told the story that they can remember cause of the mission of the game assigned them to get the score (U2D-02, 2D, P), "my mission was to basically survive until the next winter…I had to protect myself from the wolves…I need to eat birds to survive…" (U2D-08, 2D, P), "…I need to feed myself, which I am a fox in that mission. And I have to feed myself by hunting birds." (U3D-04, 3D, I). In short, designing a mission should link with the real situation that the designers want players to remember.

Things in the environment: though people may not remember the exact appearance of the things that seen in the real physical world, but they can often remember where the things are. This is the same in the VE as in the physical environment. For example, a participant remembered where the game started, which stated that the start point of the game was in the forests in the winter season (U3D-04, 3D, I). Sometimes participants could remember a number of things "…there was like two wolves right near the beginning…" (U2D-04, 2D, I). Sometimes they could remember a rough number of things, "…I walked in, and it was winter with snow, and there's a lot of rocks..." (U3D-05, 3D, I), "…being there in the Tundra environment, and so, some animals surrounding that..." (U3D-05, 3D, P).

Participants can remember or perceive the position of things in the VE "…I can remember kind of shelter. It's quite a bit below underground…" (U3D-09, 3D, P).

Changing the environment in the VE: A benefit of using VR with 3D simulation is that it can clearly show how the environment changes—for instance, changing seasons (U3D-03, 3D, P) (U2D-10, 2D, P). Players can easily distinguish how the VE changes, especially the changing of colour. Many participants mentioned they were able to remember what aspects of the environment changed in the exhibit. For example, changing of the season "…in spring it is a green, and in winter it is white colour. So, it is quite obvious for me that these two colours are different so I can remember the feature from colour." (U2D-02, 2D, P), the changing of animals' fur colour (U2D-09, 2D, I), and changing of bushes' colour (U2D-15, 2D, I).

Text voice-over instruction: The instruction style, like storytelling, shows animation with voice-over. This is an aspect of the VR experience that players can remember. It helps players remember the whole idea of the instruction (U2D-11, 2D, P) (U2D-13, 2D, P). Players understood and remembered their role in the game from the instruction (U3D-10, 3D, I). They remember the sentence in the instruction "…a long winter and short summer." (U3D-07, 3D, I). Players remembered the big picture of the environment from instruction, including things that cannot be created in the VE, for example sense of touch and the feeling of temperature"…Tundra is cold snow and like the everything is quite frozen." (U2D-14, 2D, I).

Critical situation: Players could remember the critical situation that affected their feelings during interaction with the VR exhibit. They remembered the situation going inside the cave, a situation they were unfamiliar with (U2D-13, 2D, I). They remember when they were stuck inside the cave while their energy level dropped critically low, near death, and they had to decide between hiding and leaving (U3D-10, 3D, P). Players remember the feeling of the situation when a wolf attacked and they tried to run away (U3D-07, 3D, P). They remembered trying to stay alive and survive in the game (U3D-13, 3D, I).

The transition of the game: Players could remember which situations came first and which followed (U2D-15, 2D, P). They could remember when the game transitioned from one situation to the next situation (U3D-15, 3D, P). They could remember how many different parts of a game they have played instead of the actual order. For example, a participant could not recall which season it was at the beginning, but they could tell how many seasons they had experienced (U2D-16, 2D, I).

Sound: Sound is a feature that players can remember. For instance, the warning sound (2D-12, 2D, P), and sound indicating an enemy attack "…I got (heard) the sound from the wolf that roar to come over me…" (U3D-11, 3D, P), "I just remember that when I escaped from the wolf that sound effect change to make me go quickly" (U3D-01, 3D, P).

Size of things in VE: The size of the objects in the VE, especially in comparison with the player's view in the game; makes players feel smaller or bigger. For example, regarding the enemy in game, participants said "they were quite imposing so quite big in the scene" (U2D-13, 3D, I), "…the huge wolf right next to you." (U3D-14, 3D, P), "…they came in as big creatures…" (U3D-15, 3D, P). They also remember other big things in the VE, "I saw the big screen in front of me" (U2D-10, 2D, P).

Interaction with UI: Players remember their interaction with the UI, even the simple action of clicking the button. For example, one participant reported, "…I had to select the exhibit by pointing the line onto the sign…" (U2D-08, 2D, P), "…I pressed the button and then the seasons changed" (U3D-T01, 3D, P), "…trying to get familiar with the controls inside the screen, find the start button and going" (U2D-04, 2D, P).

2) **Theme 2.2: Features that might cause players difficulty in remembering the story.**

The experiment found that some design features influence players' difficulty remembering the exhibit's story. This theme will mention what features should be considered when designing a game mechanism for learning.

An object that only appears one or two times in the game: Many participants could not remember the exact name of the bird in the story, which was mentioned only two times in the game (U2D-11, 2D, P) (U3D-15, 3D, P). However, they could remember the sound of P, the first letter of the bird's name "…P something P I cannot remember the full name." (U2D-16, 2D, P), "…I forgot, it's something with pee (P)" (U3D-02, 3D, I).

The sequence of the game is unclear when the changing state is not obvious: Many players could not remember the end part of the game (U3D-T01, P) (U2D-10, 2D, I) (U3D-10, 3D, P) because it was not accompanied by a clear state of changing of the season. It is a short transition to winter near the end of the game, and crossing the finish line does not force the players to listen to or pay attention to the message at the end wall. This might mean players did not receive the key message. And another point is that the experience at the end, the winter season environment is displayed for only a short period, so the player might not recognise this, "I think at the end it shifted for winter in a short time, right before I finished. I was surprising. But this was like winter somewhere" (U2D-09, 2D, I).

Random placement of game elements meant that some players missed them: Many players wear unable to remember wolves in the summer (U3D-09, 3D, P) (U3D-13, 3D, P). During the game, wolves and birds were randomly generated in the environment. Players saw wolves in the winter clearly at the start wall, as part of the game instructions, but due to the randomness, wolves did not necessarily appear so prominently during summer. Therefore, not all players could remember a summer wolf in the story. A participant who could not remember the wolves in summer said "…mostly wolf in the summer like they are running around in the field. Sometimes it's coming behind a rock or near the cave" (U2D-15, 2D, P). Because of this, some players could not distinguish the subtle difference in fur colour between wolves in winter and wolves in summer (U2D-11, 2D, P).

7.4.3.3 Theme 3: Features that might Influence Players' Learning

This theme focused on how players learn from the exhibit, which design features affect players' learning, and which feature is most effective in ensuring the learning of exhibit content. It will be discussed into two sub-themes:

1) Theme 3.1: Things that reduce motivation of a player to learn from VR exhibit

Players with prior knowledge about the exhibit may have decreased levels of engagement, as they may feel they do not need to learn from the exhibit. However, a good way of designing for people who have prior knowledge before is to give them a real experience related to the content, "…it didn't like to teach me new knowledge, but it kind of gave me a new experience, or it gave me maybe they gave reframed some knowledge I already had in a slightly different way, it gave me a bit more of a new perspective on some knowledge I already had..." (U2D-04, 2D, P). Players were excited to experience the virtual environment, like a new place that they have never seen before, leading to reduced levels of attention at the beginning of playing the game, during the introductory material (U2D-09, 2D, I). Players were distracted as they tried to get familiar with how to control the game, reducing their attention and ability to learn content at the beginning of the game (U2D-09, 2D, P). Players did not pay attention to reading text in the game while they interacted with the agents of the game (U2D-16, 2D, I) (U3D-13, 3D, I).

2) Theme 3.2: Content that players learn from the exhibit.

The exhibit changed players' previous knowledge and gave them more understanding of the exhibit's content (3D-14, 3D, I) (U3D-06, 3D, I). In some cases, it provided new knowledge to players, including an understanding of how to live in the Tundra environment (U3D-11, 3D, I), making clear the importance of camouflage (U3D-T01, 3D, I), learning the process of camouflage (U2D-15, 2D, I) and the actual process of looking for camouflaged animals (U2D-04, 2D, P). Players learned how animals' fur colour changes (U2D-08, 2D, P) (U2D-07, 2D, I), which is a piece of new knowledge to players "…the wolf changed its fur for camouflage, and the birds do as well. That's a new thing for me" (U3D-05, 3D, I). Players learned how foxes survive (U3D-04, 3D, I) and how foxes hunt birds in the environment (U3D-01, 3D, I). Players learned foxes could be predators and prey at the same time in the environment (U2D-14, 2D, I), and learned how foxes hide from predators (U2D-07, 2D, I) (2D-03, 2D, I).

7.4.3.4 Theme 4: Features Effect on Players' Emotion

This theme focuses on how the design features and game mechanics impact players' emotions and which features involve players' emotions with the story in the game. This experiment found that players' emotional attachment to the game occurs in both designs, the 2D view and the 3D view. It is discussed below for each emotion.

Scared or afraid: Game characters might make players feel scared, for example, due to the big size of the enemy (U2D-13, 2D, I). Players felt scared seeing a big wolf (U3D-06, 3D, P) (U3D-11, 3D, P). The big size of the enemy compared with the players made them feel very small (U3D-07, 3D, P), especially in the VR 3D environment, where players reacted to feeling scared of the enemy the same as they would in reality (U3D-07, 3D, P). Players felt scared when the enemy attacked (U3D-05, 3D, P) (3D-10, 3D, P). This feeling forced them to hide "…And also when it comes closer than I felt scared a bit scared. And after that I have to run away and hide myself with the cave…" (U3D-11, 3D, P). Players felt scared when they heard the enemy's sound, they were scared of the wolves' sound (U3D-04, 3D, P) (U3D-09, 3D, P). Players felt scared when they heard the wolf roar (U3D-02, 3D, P).

Players felt scared of the enemy because of the game's roles (U2D-07, 2D, I). They did not want to get caught by the enemy to lose their score (U3D-07, 3D, P). The feeling of fear made players avoid getting close to the enemy, and they tried to run away (U3D-07, 3D, I) (U3D-13, 3D, I). This feeling sometimes induced players to not follow the instruction in the game, making the player miss some experience or situation that the designer created for them in the game. For example, the game's instructions asked players to walk along the pathway, which aims for them to meet the enemy, to hide, and to seek the birds. But the players thought this way was a trap that would cause them to meet many wolves, so they did not follow the instructions and decided to go another way (U2D-04, 2D, I).

Excited: Players were involved with the game, and they feel excited when they see enemies (U2D-04, 2D, I) (U3D-07, 3D, P). They felt excited when the enemy moved fast and attacked them (U3D-12, 3D, I). They felt excited when they saw many wolves at the same time "…I felt a little bit excited, because I think that there are a lot of wolves over there, I have to hide myself from them." (2D-02, 2D, P).

Surprised: One of the game mechanics that could make players feel surprised is when players can find a hidden object: "I would walk up on along the path and then find that there was one (wolf) in front of me already, which was kind of like a nice surprise...when I was trying to walk along the route … just hadn't seen him until he got right up close, which was kind of a nice surprise" (U2D-04, 2D, I). A participant reported that they felt surprised when they saw the enemy (U2D-07, 2D, I). The enemy's big size also surprised players (U2D-13, 2D, P).

Fun: The players' role required them to be alert and responsive, which made players feel enjoyment. They stuck to their role in the game in their response to each situation. For example, players reported they must hide when they hear a wolf come to attack. This role play made them feel enjoyment (U3D-14, 3D, P). Players felt interested in seeking something hidden (U2D-04, 2D, I). Players felt more fun finding something hidden, "…the ptarmigans were kind of hard to spot sometimes, and it was kind of fun to find sometimes" (U2D-04, 2D, I).

Arousing interest to play: The scoring mechanic was meant to engage players to play. The score in the game is a motivator for players to compete in the game [81], engaging players to play the game (U2D-02, 2D, P). The additional sound alert features provided more encouragement to players to play the game (U2D-12, 2D, I). Fighting with a difficult situation also challenged players to play the game (U2D-02, 2D, I).

Stressful or unhappy: Players felt unwilling and had decreased motivation to play if the game was too punishing too early (U2D-04, 2D, I). The sound alarm is one of the game mechanics designed to engage players to play the game, but sometimes players could not make the sound alarm stop because of the difficulty of the game. This made players feel unhappy, "the alarming sound was unpleasant. I hated that" (U2D-09, 2D, I).

Anxious, nervous: Players felt nervous about dealing with a situation where the wolves moved to attack the players. The reaction of wolves inside the VE is quite realistic, especially in the 3D view (U3D-T01, 3D, P) (U3D-10, 3D, P). This kind of feeling of nervousness in the game stays long in the players' memory, "…I felt that same feeling again, imagining the wolf coming down and coming to eat me…that bit of nervousness, I can feel that a gain now." (U3D-T01, 3D, P).

Other feelings: Players felt empathy for the foxes because they played a role of a fox in the game (U3D-06, 3D, P). Players felt impressed when they saw an agent (the wolf) that they like (U3D-01, 3D, 1). The big wolves gave players a sense of enemy threat (U3D-09, 3D, I) (U2D-11, 2D, P). The VR HMD gave players immersion in the VE (U2D-02, 2D, P) (U3D-05, 3D, I), the examples participants mentioned about their experience include, "… there's actually I'm surprised how much I can remember it, because it's quite an immersive experience" (U2D-13, 2D, P), "…Then in terms of the general experience, I would say, at some point, I really felt as if I was in the physically like I was there with all the other animals and stuff" (U3D-10, 3D, I).

Feel uninvolved with the game: Some players did not feel involved in the story of the game. They were not scared of the wolves because they realised it was a game (U2D-09, 2D, I) (U3D-03, 3D, P) (U3D-15, 3D, P). Another reason reported for this was that the wolves' behaviour and movement were not realistic (U2D-04, 2D, I) (U2D-14, 2D, I) (U2D-16, 2D, I). The movement of wolves was very slow (U3D-15, 3D, 15), and players paid attention to other things rather than the enemy (U2D-16, 2D, P), "…I was not very careful about wolves. I was more focused on eating birds" (U2D-07, 2D, P).

7.4.3.5 Theme 5: Features' Effects on Player Interpretation

This theme focused on the VE features that might affect players' interpretation during play with the exhibit. Some experiences were not intentionally included in the design of the exhibit, but players used their own interpretation of the VE to gain these experiences. The results of the experiment suggest how aspects of the VE design may affect players' interpretation of the game's story. These are summarised as follows:

Effect of environmental feature: the environment's reactions to the player's interactions influence how the players interpret things in a simulated environment. How similarity its reaction corresponds to behaviour in the real world, influent the player's thinking (U2D-02, 2D, P). (U2D-07, 2D, P) (U3D-15, 3D, I). For example, they felt safer when hiding behind rocks and caves, "…in the grass not so much (safe)…but safe in probably behind rocks and caves" (U3D-02, 3D, P). Players decided to interact with things similar to how they thought about them in the real physical world and also based on their interpretation of the VE (U3D-03, 3D, P) (U3D-15, 3D, P) (U2D-11, 2D, P).

The actual size of the environment made people have reasonable interact with things in the VE "…that is there the hole in the cave the wolf cannot enter because that hole in the cave is fit to the size of the fox" (U3D-04, 3D, P). In contrast, due to the unnatural behaviour of the VE, players cannot recognise the simulated situation. For example, players can not recognise daytime and nighttime in the game because, at nighttime, the sky is not dark (U2D-14, 2D, I) (U2D-16, 2D, I) (U3D-07, 3D, I).

Misunderstanding because of action in the game: Players misunderstood the meaning of things in the VE because they faced a situation where the reaction of the objects in the VE, and their interpretation of this, lead them to misunderstand the situation. For example, one participant felt comfortable hiding in the tall grass and behind the trees, and stopped to hide up on the hill, because previously they were eaten by a wolf (U3D-T01, 3D, P). However, this area was not designed for hiding.

Effect of sound: Players interpreted the meaning of sounds in a different way based on their interpretation of the situation they experienced. For example, "…when they (wolves) get a close up I got the sound "cook cook" I do not know it was the meaning maybe it means I died" (U2D-12, 2D, I). A participant said the alert sound meant the wolves saw them, "…I want to know how to avoid the sound alert, I tried to run and try to move, and I try to hide (behind) rock and sound is not stop…The sound means the wolf see you that I understand it" (U2D-16, 2D, I).

Effect of time playing the game: players experience long or short times in the game, depending on whether they follow the pathway created for them. Sometimes, when they did not follow the instructions and created their own pathway to explore in the game, they played for a longer or shorter time, depending on each player's journey. This affected how the player understood the time period in the game, "…I walk out the way so I think this might be the case that I feel like in the summer also long." (U2D-07, 2D, P).

7.4.3.6 Theme 6: Features that Influence the Quality of User Experience

This theme focused on design problems that affect user experience. Participants here reported a number of problems that affected their experience of the game. The problems come from many factors.

Game controls: A delayed response after players pressed a button or took an action in the game made players confused about controlling the game. It made them feel unsure about using the controller (U2D-02, 2D, P) (U2D-T01, 2D, I). The difficulty in controlling the game made players uncomfortable (U2D-04, 2D, I). Players felt confused using the controller to play the game, because of conflicting previous experience of using the controller to control a game. The mapping of buttons to actions did not correspond with the mapping that the player had used previously , "…I prefer to use the index finger as a selection because this is normally our index finger when we touch the browser in the smartphone, but this one it switches to the middle finger, so I have some mistake a lot in how to select and how to turn" (U2D-02, 2D, I). Players were confused about using the two colour pointers that are active at the same time for interaction in the game for the 2D view. It was difficult to control, and players forgot that they had to use the pink beam or the red beam (U2D-03, 2D, I) (U2D-10, 2D, P) (U2D-15, 2D, I) (U2D-T01, 2D, I).

Sound in the game: Players did not understand what triggered the sound alert (U3D-13, 3D, I) (U3D-07, 3D, I). Players felt annoyed or stressed by the sound alert because of the speed or frequency of play. For every 15 points drop (U2D-14, 2D, P) (U2D-04, 2D, I), the alarm sounded very loudly (U3D-05, 3D, I), and players did not know how to stop the sound (U2D-11, 2D, I). However, when designing the alert sound, there should be a balance between warning the player and making them feel annoyed (U3D-13, 3D, I). Some recommend improving the sound, perhaps using more natural background sounds (U3D-05, 3D, P), or adding the sound of footsteps when the player (fox) walks (U3D-06, 3D, I) (U3D-T01, 3D, I).

Player specific problems using VR HMD: Many participants who wore glasses reported that they suffered some problems in the game. For example, they could not see any of the writing text in the game (U2D-T01, 2D, I), their glasses fogged so they could not see things in the game (U3D-14, 3D, I), or the HMD did not fit with the player's head (U3D-01, 3D, P).

Image display quality: Many participants mentioned they felt dizzy because of the speed of displaying the image in the VE (frame rate speed). They reported the VR screen lacked images, and sometimes the pictures shook due to lagging (U2D-02, 2D, I). Sometimes the pictures were disrupted and did not cover 360 degrees. It made players felt dizzy (U2D-03, 2D, I). Players felt nausea if the picture in the VE was not clear (U3D-01, 3D, I). Players felt dizzy if the pictures were not synchronised when zooming in or zooming out. This meant players' eyes could not focus which made the pictures blur (U2D-12, 2D, P).

7.4.4 Player's behaviour and their Interaction with the Game in 2D View Versus 3D View.

Figure 7.11 Shows examples of players' behaviour while playing the game and compares the perspective between the 2D view and 3D views perspectives.

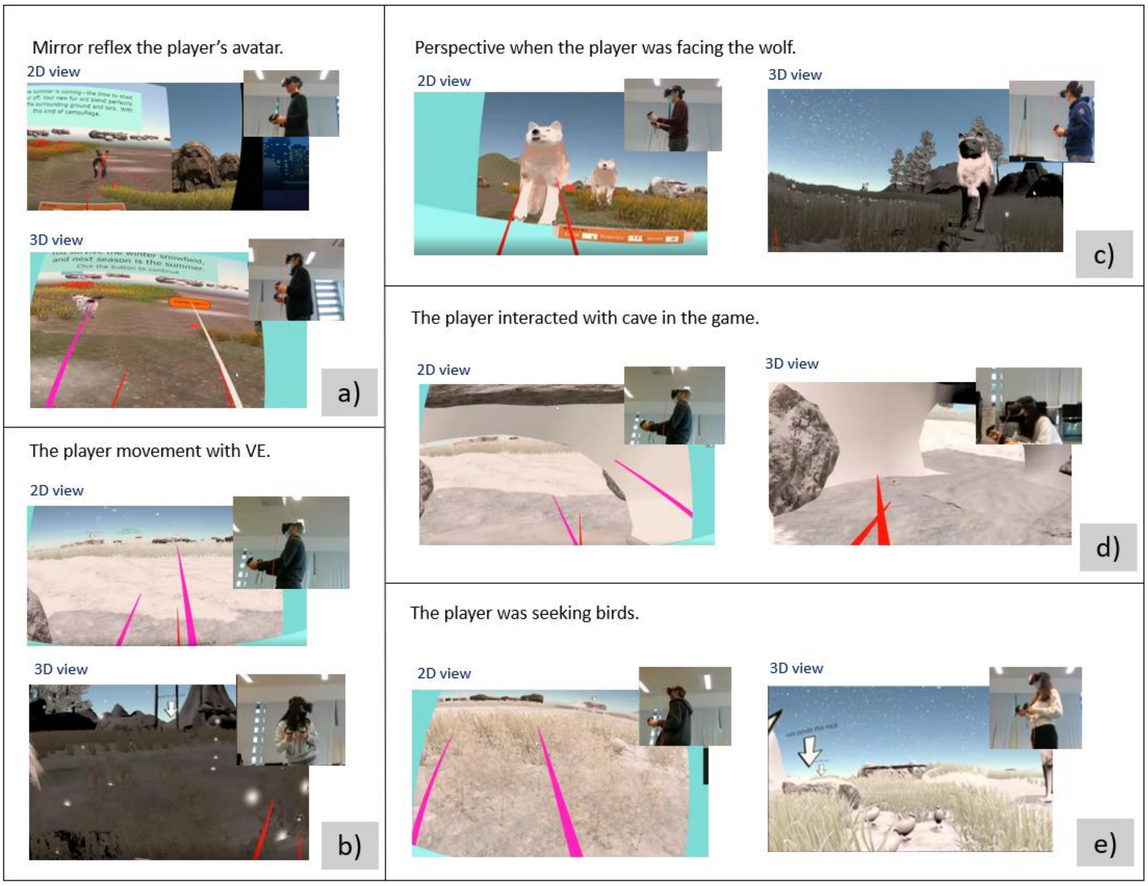


Figure 7.13 Examples of players' behaviour interacting with game and perspective in game, comparing between 2D view and 3D view. a) Players' perspective when mirror reflects their avatar. b) Players locomotion in VE, 2D view using controller to rotate the view in game, while 3D view players used whole body movement in game. c) Player's perspective when was facing the wolves in game. d) Players interaction and reaction when inside the cave, players who play 3D trend to sit down while inside the cave. e) Players' perspective when was seeking birds.

7.5 Discussion

This experiment aims to investigate how the 2D view design and 3D view design affect user experience. The study measured user experience based on learning, memory, emotion and immersion. The researcher created a game that gamified the learning. The game allowed players to play the role of a fox to survive in the Tundra environment. The game is designed to encourage players to interact with the environment and agents inside the game, to seek birds and hide from wolf attacks. The game provided a scary feeling of a wolf's attack and simulated a critical situation for players to make a decision between two things. These kinds of situations make players feel aroused and it is believed that the arousal will cause players to remember the story better than the neutral feeling mentioned in the study of Costanzi et al. [39].

The results show that learning and memory are not dependent on the 2D view or the 3D view, but the difference between the 2D and the 3D view affects immersion and emotion. The results found the 3D view provided a more immersive experience to players and influence players' emotions more than the 2D view. The following section will explain and discuss these results.

7.5.1 The 3D View and the 2D View are Equally Effective for Players Learning Content in VE.

The results show no significant difference in knowledge gain from the 3D view and the 2D view. The idea of experiential learning, "learning is the process whereby knowledge is created through the transformation of experience" [14] helps to explain why the 2D and 3D design view in the VE have the same potential to support players learn the exhibit's content and knowledge retention. People learn new things through their experiences with the environment surrounding them. The two versions of the game, the 2D view and the 3D view, have the same scientific content and the same activities. In the interviews, participants reported that they gained their knowledge from listening to the voice-over text explanation in the game and their interactions when playing the game. From this viewpoint, they shared the same experience and gained the same knowledge. Despite this, the 2D view and 3D view provided significant differences in immersion and emotion.

Moreover, the retention rate between the post-test and after two weeks test did not show significant differences in the 2D view and 3D view. Semantic memory refers to the knowledge and facts that are stored in the human brain [183], meaning that the knowledge players obtained from the VR exhibit will remain in semantic memory, which is one type of long-term memory.

The game mechanics lead players to repeatedly perform the main activities in the game, eating bird and escaping wolves. The repetition assists players in learning and retaining the knowledge in their memory [8]. Prior research suggests that emotion plays a significant role and should be engaged in learning, and that reality provides real emotion to the learner [14].

The results of this experiment show that both the 2D and the 3D view can stimulate players' emotions, albeit to a different extent.

In this case, both view design, 2D and 3D has same potential offer player to gain knowledge from the exhibit's content. In spite of the fact that 3D view provides immersion to player more than 2D view. The result shows that immersion did not affect players' learning to gain knowledge from exhibit, which similar to result found in the study of Mahmoud et al. [132] .

In summary, the 2D view and the 3D view offer learning to players at an equal level for the same design of the experience (activities, narrative story, and game mechanic). The design of the exhibit's content to create an experience for players influent the potential of a VR exhibit to provide players to gain knowledge. Increasing immersion and emotion did not affect players' learning and gaining knowledge from the exhibit's content.

7.5.2 The 3D and 2D View have the Same Potential to Support Players in Remembering the Exhibit's Story in VE.

Humans learn and memorise things in the environment via senses such as touch, sight, hearing, smell, and tease. It involves three processes: encoding, representation and retrieval. The memory of an event that humans experienced in the past is stored in the long-term memory called Episodic memory, while Semantic memory stores facts, ideas, concepts, and the knowledge that a human learns about the world [183]. The result from this study shows that the 2D and the 3D view were not significantly different in supporting players to remember the exhibit's story and events even though both designs offer different immersion and emotional factors. This means immersion and emotion might not have a direct effect on memory in this context. However, others study found immersion and emotion relate to memory.

In contrast, a study found the use of a VR HMD system, which offers a sense of immersion to learners, improved recall of episodic memory more than the non-immersive system [80], while another study found that immersion affected memory but this depended on the characteristics of immersion [201]. Psychology scientists have found that emotion is an essential component of episodic memory [183]. Another study mentioned that the positive and negative arousing stimuli induce are more memorable than neutral, non-arousing, stimuli

[39]. A reviewed relationship of emotion influent on learning and memory in the study of Tyng et al. [213] mentioned that emotion did not always affect learning and memory. It depends on various factors, for example, different modalities of emotional stimuli and the emotional effect of emotional multimedia content. And Tyng et al. [213] mentioned that positive emotional content was remembered more than negative content, and the negative valence impact memory, which prevents implicit memory.

In contrast, the study here shows emotion did not affect remembering content from 2D view and 3D, can give a reason to this case because both views offer the same content and experience; although they show significant differences in emotion, but both views trend induce more positive emotional rather than negative as the results from this study show. In which the positive emotion enhances memory.

According to the results from the interviews, most participants reported that the active learning experiences in the VE (including their interaction, activities, game mechanics, and the perceived reality of the VE) helped them to remember. The things that stuck in participants' memory are the activities of trying to seek birds, running away from wolves, and feeling when the wolves were attacking them. From the results, the 3D view and the 2D view provide a sense of immersion and influence the player's emotions. The 3D view offers more immersion and a higher level of emotion than the 2D view. Immersion and emotion, stimulated through interaction with the VE and agents in the game, here appear to have a minimal effect on memory. More important for creating lasting memories are the game mechanics used for the exhibit, and meaningful storytelling.

In short, the 2D view and the 3D view equally support players to remember the story and activities of an exhibit for the same design of experience (activities, interaction, gamification mechanism, VE). The results from this study suggest that increasing the level of immersion and emotion does not affect memory. However, the results show significant differences offer emotional arouse, attention, and afraid factor between the 2D view and 3D view in which the 3D view produces these emotional factors than the 2D view.

7.5.3 The 3D View Produced More Immersion than the 2D View in the VE.

The 2D view shows significantly lower levels of immersion than the 3D view. Two assessed aspects of immersion received scores less than 50% for the 2D view: item 5, ‘perceives my body’ which indicates players feel less self-embodiment with the avatar in the VE, and item 6, ‘naturally interacts with the object’ indicate that players less feel natural control the object unlike in the real world. The reasons for this are as follows. The 2D view was designed as a flat-screen display wall in the VE. Controllers are used for avatar movement and pan view in the game, as opposed to walking and turning the head and body. So, these factors result in less freedom of movement in the VE. At the same time, the 3D view players interact with the VE via a whole body (that of the fox) in the full 3D virtual environment. Therefore, it offers players more embodiment with an avatar than the 2D view, which uses the VR controller to control the avatar in the interactive wall. Therefore, 2D view player experienced less immersion.

While the 2D view offered less immersion than the 3D view, it still provoked players’ emotions, and players could feel immersed in the game. To explain why the 2D view still offered an immersive experience to players, consider the influence of surrounded or panoramic views on immersion: a view of a wide area evokes players’ emotions more than a narrow view [98]. The size of the screen displaying media affects players’ experience when interacting with a game. The larger screen produces a higher sense of being in the game, greater arousal, greater mood change, and results in more enjoyment than a small screen [91]. The size of the interactive wall is huge compared with the size of the player’s avatar in the VE; as a result, the 2D view was capable of delivering an immersive sensation to players.

To summarise, the 2D view decreased immersion relative to the 3D view. When designing a 2D view in the VE, the interactive wall should be big enough for players to feel the surroundings of the VE in the game.

7.5.4 Immersion and Emotion

The results from this study indicated that the 2D and the 3D views offer significantly different immersion and emotion to players. The 3D view provided higher immersion and emotion than the 2D view. The results indicate that both immersion and emotion have a consistent impact on players' experience, and high immersion produces high emotion. This was especially true for players who experienced the 3D view. They stated that they felt scared and afraid of the wolves in the story. A high degree of reality in the situation created by the game affords real emotion to players [14]. As a result, players' emotions will be more involved with the story in the exhibit if players feel more immersed in the VE. These findings are similar to those found in [223]. Another study showed players who use VR HMD experience more emotion than players who play the same game using an Xbox with a conventional 2D display, with the Xbox condition resulting in less immersion than VR HMD [128].

It is not the immersion itself that evokes players' emotions; without a meaningful narrative story, virtual environment, and game mechanics that create the situations players experience, the exhibit could not deliver meaningful emotions to players. In fact, Baños et al. [12] found that immersion is less important than the content design in evoking emotion. This study suggested that if media intends to evoke players' emotions in order to, for example, raise their awareness of the natural environment and make them change their attitude, it should use a VR exhibit with a 3D view rather than a 2D view, as this affects players' emotions more easily than the 2D view design.

In short, immersion and emotion are related. Media that produces more immersion tends to better evoke players' emotions. However, the design of content in creating an experience for players is more important to influence players' emotions than creating media whose only intent is immersion.

7.5.5 Suggestions for Designing Content for an Exhibit in a VE.

1) Multimodal media design: the combination of media modality (presentation form), i.e. activities *and* text voice-over explanation helps players obtain knowledge more than using only one mode. For example, if the design only provides activities without text explanation, players might interpret the context of an activity differently depending on individual experience, especially in the 3D VE. From the results, many aspects of the VE affect players' perceptions, and players feel and react to things in the VE in a similar manner to how they respond to something in the real world. Furthermore, if the design uses more text and images, and fewer activities, this may reduce the capability of players to remember the story and their experience.

2) The clear changing state of the sequence in the game: an unclear changing state in a game affects players' memory of the sequence of the story. For example, many participants could not remember the end part of the story because the end part of the game was not clearly announced, and there were no actions required of players at the end. As a consequence, players did not recognize the concluding message by which the media aimed to evoke players' emotions in relation to the story. Thus, it is recommended that, if the sequence is important to understand, the game's design should clearly indicate the changing state of the game and notify the player of their progression in the game.

3) Being aware of designing content that relates to changing the appearance of the player's avatar in the VE: the players' perspectives in a VR are designed in first-person view. A design learning content that involves changing the avatar body might affect players' perception of the content. For example, in this experiment, the player's avatar is a fox; the player could not see changing effect on the fox's body, so a mirror is provided for them to see their body reflection. It was not the most efficient way to solve the problem and allow the player to see their body. Sometimes, players were not close enough to the mirror or did not stand at the right angle allow them to see the reflection of their body. As a result, they lost a piece of important information - the fox's fur changed colour. Thus, the design should set up a scene that makes sure the player can precisely see their avatar.

4) Alert sound design: Alert sounds or warning sounds in the game has an aim to motivate players to play. Sound should be used at an appropriate point in the game and used for an appropriated length to notify players. Participants reported that the alert sound made them annoyed and made them feel stressed. Some participants did not understand the reason for the sound alert. The game uses earcons sound to warn players, which might cause players to be unclear about the meaning. Ng and Nesbitt [148] suggested that an alarm including speech and earcons together allow make players to better understand the meaning. In addition, the sound characteristic influences human feeling, "Melodic sequence with consonant relationship is more pleasing than dissonant one. Some sound spectra are more annoying or attention grabbing, while other produce a sense of happiness and well-being" [58]. Therefore, sound should be carefully designed for a game and an exhibit.

To conclude, when designing an experience for players (choosing content, narrative story, game mechanism, VE, and the meaningful interaction of the game), it more beneficial for learning and memory to evoke players' emotions than to merely create immersive media.

7.6 Conclusion

This study aims to investigate the design of content in a VE and compare the use of a 2D and a 3D view and how this affects user learning and memory. This experiment uses two different view designs in the VE to investigate user experience. The two design cases include the 2D view, a flat-screen display in the VE, and the 3D view, the full VE. This experiment used a game designed by the researcher to educate about camouflage of animals in the Tundra environment. The player plays the role of a fox whose goal is to survive over one year in the Tundra by hunting birds and avoiding wolf attacks. The experiment used a between-subject design by recruiting 20 people per group. However, only 16 participants per group could join the actual experiment. The final results for the 2D view are based on 14 participants, and, while those for the 3D are based on 15 participants. These are the number of participants able to complete all the steps in the experiment.

The experiment used both qualitative and quantitative research methods. The qualitative assessment measured user experience based on four factors: learning, memory, immersion, and emotion. The researcher created a test on the game's content to assess players' learning and memory. The participants were assessed on learning three times: pre-experiment, post-experiment, and after two weeks. The participants completed a memory test after the experiment and again two weeks after their experience with the exhibit. To assess immersion, a self-report questionnaire was created by the researcher, with the items developed to evaluate the effectiveness of creating a sense of reality in the virtual world. The emotion questionnaire used Affect Grid and PANAS to assess players' emotions. The qualitative assessment also used a semi-structured interview conducted immediately after experiencing the exhibit and again two weeks after experiencing the exhibit.

The statistical results show no significant difference in players' learning and memory between the 2D view and the 3D view but found significant differences in immersion and emotion factors. The 3D view offers higher level of immersion and more effectively evokes players' emotions than the 2D view. The players demonstrated a significant gain in knowledge after having experienced exhibits using both the 2D view and the 3D view. The 2D view showed a decreased level of immersion relative to the 3D view, but this did not translate to a significant effect on players' learning and memory. According to the result, this might appear to suggest that immersion does not have a significant effect on memory. However, it depends on character design of content for the learning media. Immersion combined with high quality content design can evoke emotion in the experience provided by the media. Emotion is an important factor that encourage players to learn and empowers encoding of information into memory.

Finally, the results suggested that design content is crucial for a VR exhibit. The experience design (which includes content, narrative story, game mechanism, activities, and a meaningful interaction of the game), influences players' learning and memory of content more so than simple use of improved technology. However, if the exhibit intends to evoke players' emotions, the use of a 3D view design is suggested, as this offers more immersion and emotion than the 2D view.

Chapter 8 In the Wild Study to Evaluate the Proposed Framework.

8.1 Introduction

This study conducted an evaluation of the proposed framework in the wild study to validate the proposed framework in the real museum setting. The in-the-wild study offered the researcher a better understanding of the context in that technology will be used and the impact of the museum environment on the technology. It allowed the researcher to gain insights into user behaviour and how people use and adapt to technology. Running *in situ* studies further offered the researcher the chance discover unexpected findings about what people might or might not do when using a new technology [175] [176] [32]. The components to design a new VR exhibit of the proposed framework include Content design, Action Design, Social Interaction Design, System Design, Safety and Health. This study especially evaluated the System Design, and the Safety and Health components of the framework in the naturalist setting inside the museum environment. The results were used to validate design components and factors of the proposed framework and provide additional suggestions and information for designing a new VR exhibit.

This chapter starts with Section 8.2 outlining this study's goals, then Section 8.3 explains this study's design, setup device and area, participants, measurements, and procedure. Next, Section 8.4 shows both quantitative and qualitative results, and Section 8.5 discusses the interpretation of what this experiment found. Finally, Section 8.6 will summarise the information of this study.

8.2 Study goals

The study aimed to validate the proposed framework deployed in the museum and gain insight into understanding user behaviour when interacting with the VR exhibit. To discover issues beyond those found in a controlled lab, in which visitors will naturally interact with a VR exhibit set up in a museum environment. Two VR exhibits from the previous studies were adjusted to the system design, which covers features that were suggested in the proposed framework as much as possible. These were then evaluated with visitors inside the museums. This study investigated user experience using VR exhibits in museum settings as follows:

1) How do visitors accept and adapt themselves using VR devices, to determine how visitors' opinions using VR HMD and VR controller regarding comfort and ease of use of the VR technology.

2) The suitability of the design of VR exhibits for public use in the museum context. To examine how the design of content and interaction of VR exhibits can be suited for museum use and how easy it was for visitors to interact, understand, and remember how to use the exhibit.

3) The management of exhibits suitable for the use of VR in museums. To validate the composition of the System Design and the Safety and Health of the proposed framework in terms of the functional and well organised technical components, use of space, supporting museum staff to maintain and run the VR exhibit, and supporting visitors' convenient and safe access to the VR exhibit.

4) To examine whether or not the VR exhibits require staff management and help visitors use the exhibit, as well as establish role the floor staff have in the VR exhibit?

5) To validate and confirm the usability of the social interaction design for VR exhibits in museum settings, in the case of asymmetric connection players using VR and PC from Study 2 (Chapter 6).

In this study, participants were asked to play a VR exhibit and give their feedback on the exhibit. In addition, the behaviour of their interaction while playing the VR exhibit was observed. Participant feedback would help the researcher validate the usability of the proposed framework through each VR exhibit. The result was used to improve the proposed framework for designing a new VR interactive exhibit. This provides an opportunity to analyse each exhibit as a case study before giving an example of VR exhibits to each museum, as seen in next study.

8.3 Study Design

8.3.1 System Design

The first step of the study recreated the VR exhibits used in previous studies in this research. Features were adjusted according to the System Design in the proposed framework and installed in the VR headset. The VR exhibits were set up in the exhibition hall and allowed visitors who met the criteria of the study to experience the VR exhibit, before asking them to give feedback in a self-report questionnaire. The experimenter observed visitors and how they interacted with the VR exhibit and examined the issues experienced when using the VR exhibit.

The VR exhibits include:

1) Steam engine VR exhibit: The VR Exhibit from Study Two, design cases 2: symmetric design VR and VR, and design cases 3: asymmetric design VR and PC. The learning content of the exhibit is about the steam engine. It is an example of a co-player VR exhibit, single-player, and single task.

2) Camouflage VR exhibit: The VR exhibit from study three, learning content of the exhibit about Camouflage. It is an example of a co-present using a wireless connection, multiplayer, and multi-tasks.

The user interface of both exhibits was modified by adding a feature that can return the user to the home page, which has three mechanisms:

1) The static home button shows on the game scene.
2) The pop-up home button that shows when the player presses the A button to activate it appears.
3) The automatic reset of the system back to the home page if the system becomes unresponsive for too long.

These feature aim to help floor staff manage the VR exhibit for each player. The instruction was translated into the Thai and English.

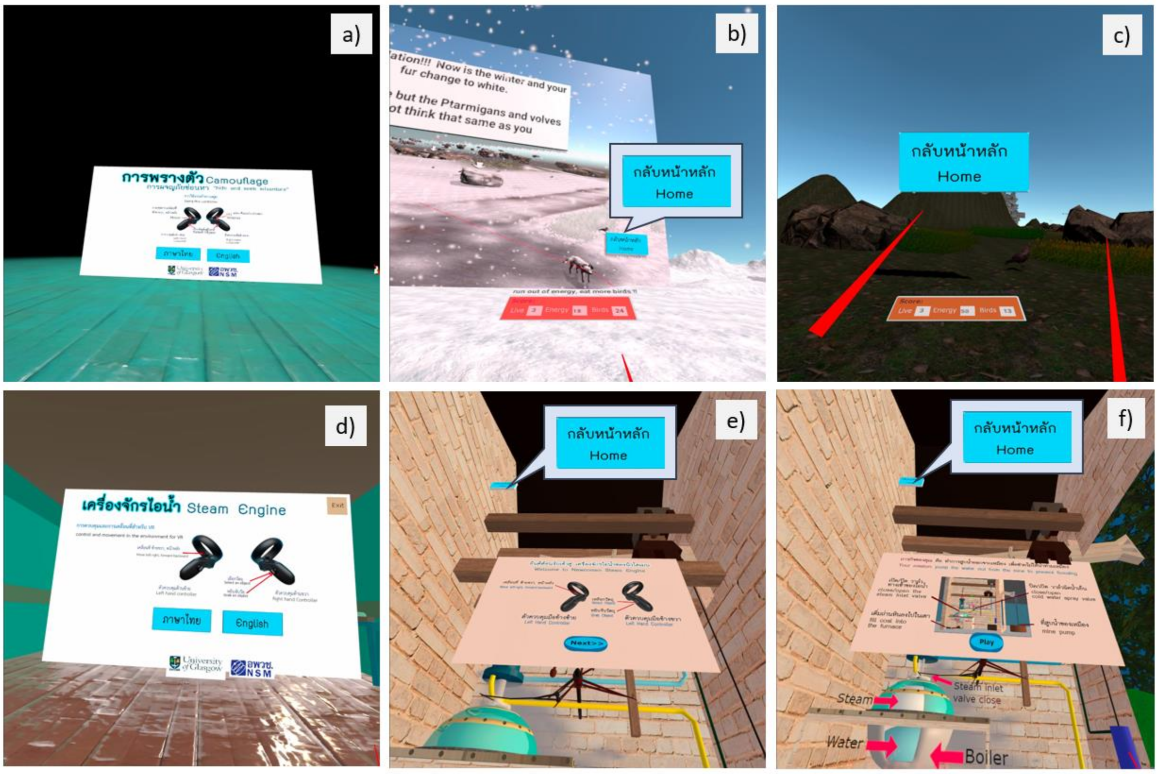


Figure 8.1 Example of modified UI to adding features help floor staff to manage the VR exhibit. a) and d) are the home page which include instruction to use the controller and the language select option Thai of English. The b), e), and f) are the static home button shows on the game scene. And the c) is the dynamic button, it displays when the user press A button on the controller.

8.3.2 Setup Device and Area

The study was set up inside the Rama IX Museum and Science Square. The researcher created an area for running the study and put an information board at the entrance. The researcher created a play area of 2x2 square meters for a player to stand inside while experiencing the VR exhibit. The devices for the setup Camouflage VR exhibit included one PC monitor screen, one Oculus Quest 2 HMD, one play area, one chair, and a USB cable for streaming content from the headset. The devices for setup of the Steam Engine VR exhibit include one PC monitor screen, two Oculus Quest 1 HMDs, one microphone, one keyboard, one mouse, two chairs and two play areas.

In the experiment, the researcher designed a set-up to best provide a usable system for players to play and floor staff easy to manage the exhibit. The setup system in the experiment used a cable connection and a chair to keep the headset in the middle of the play area to avoid guardian loss; if guardian loss occurred, floor staff would need to recreate it again.

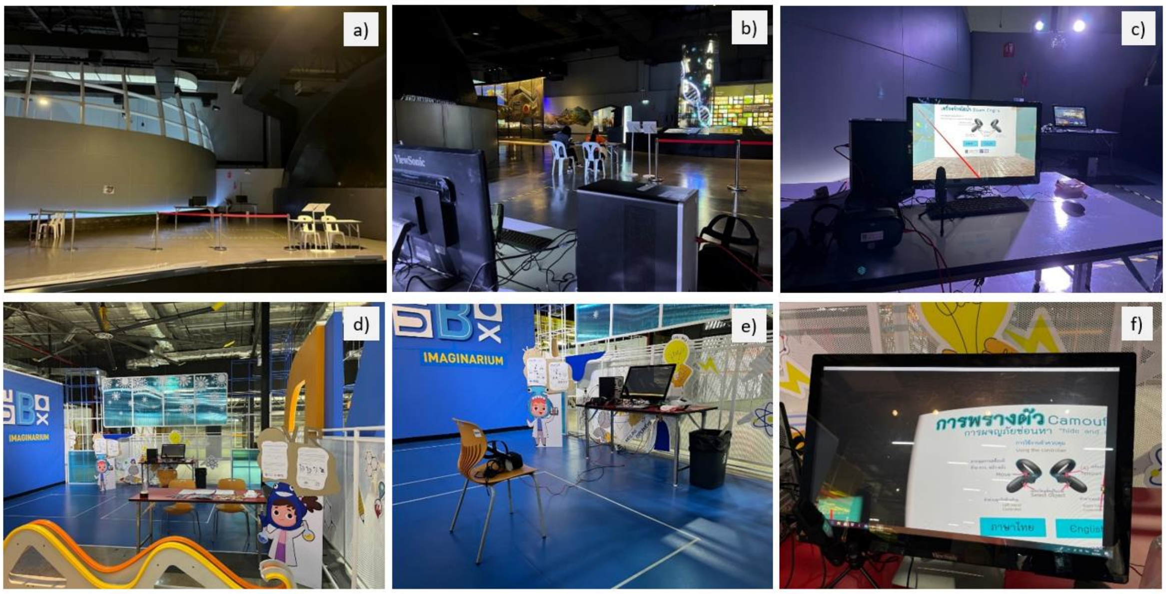


Figure 8.2 Set up area and devices to run study. a)-c) The system setup at RAMA IX and d)-f) the system setup at Science Square. c) The exhibit installed on PC provide for visitor to play with another visitor who wear VR HMD. f) The PC monitor display content that stream from VR HMD.

8.3.3 Participants

Each VR exhibit is used within the subject study. The experiment expected to gather data from 30 visitors for each exhibit. Visitors aged 18-60 who visited the Rama IX museum and Science Square were invited to participate in the study. The researcher put the invitation board and information about the study in front of the study area in the exhibition hall.

8.3.3.1 Participant Demographics

The Camouflage VR exhibit gathered data from 31 participants aged 20-60, 19 male and 12 female. Eighteen participants had never used VR before, twelve participants rarely used VR, and one participant used VR at least three times per week. Twenty-two people use PC computers every day. Fourteen people felt dizzy after playing with the Camouflage VR exhibit.

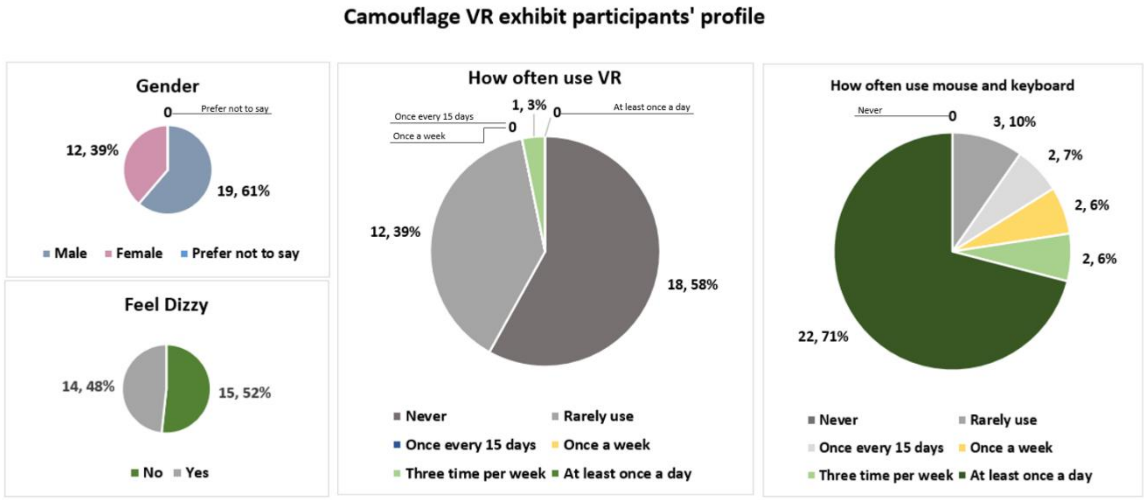


Figure 8.3 Participants' background information of Camouflage VR exhibit.

The Steam Engine VR exhibit gathered data from 29 participants aged 22-47, 18 male and 11 female. Eighteen participants had never used VR before, eight participants rarely used VR, one participant used VR at least three times per week, one participant used VR at least one time per week, and one participant used VR at least three times per week. Twenty people used personal computers every day. Eleven people felt dizzy after playing with the Steam Engine VR exhibit.

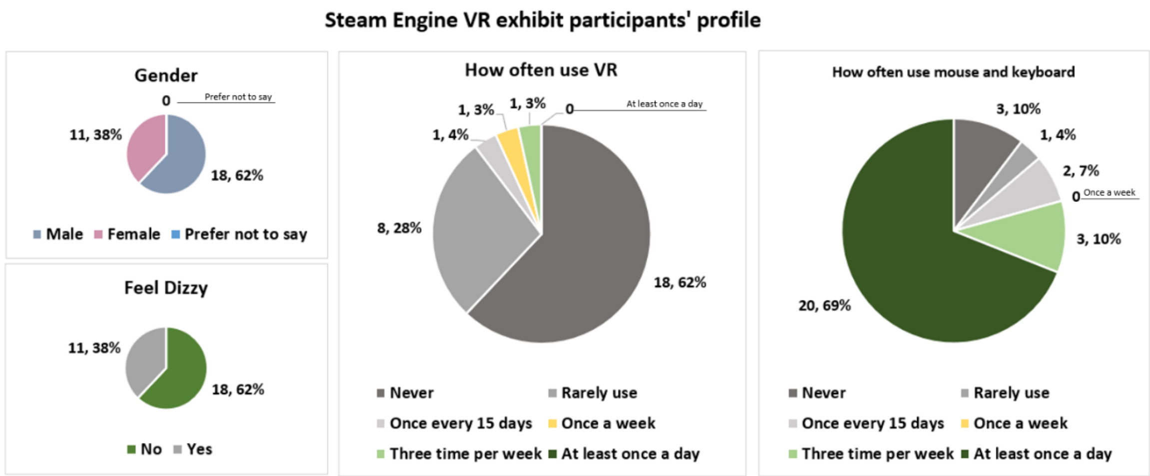


Figure 8.4 Participants' background information of Steam Engine VR exhibit.

8.3.4 Measurement

This study used quantitative and qualitative measures to validate the proposed framework through usable VR exhibits. The exhibit was created to meet the factors in each component of the proposed framework as much as possible. To measure users' satisfaction with interacting with the exhibit and how successful deployment of the exhibit in real environments was, by used 4 measures [33]. The measurement applied from the usability measurements model mentioned by Seffah [187], which focused on 1) *Satisfaction* factor refers to how the user feels when using the system, i.e., the user is satisfied or happy to play with the exhibit. 2) *Learnability* refers to how quickly the user learned to interact with the new exhibit. It enables researchers to measure if the interaction design is easy for visitors to interact, learn, understand, and remember. 3) *Effectiveness* refers to the exhibit enabling visitors to perform tasks with accuracy and without error 4) *Safety* refers to limiting the risk of harm to people. It indicates that the exhibit's management is safe for visitors and helps museums reduce any risk from using the technology. This study also measures how visitors accepted and adapted to using the VR device to explore visitors' opinions using VR technology.

The self-report questionnaire has three parts. The first part is surveys general demographics about the visitor, including age, gender, and familiarity with using VR and PC. The second part is a self-report questionnaire with a five-rating Likert point scale (1 strongly disagree, 3 neutral, 5 strongly agree) to measure the user's experience using the VR exhibit. The third part consists of open-ended questions to gather visitor feedback and recommendations. The questions in the self-report questionnaire are:

VR Technology:

- How easy is it to wear the VR headset?
- How easy is it to use the controller?
- How comfortable is wearing the VR headset?

Content and interaction design:

- How easy is it to interact with the game?
- How easy is it to learn to play the game?
- How easy is it to remember how to interact with the game?

- Is the time of playing the game suitable for using VR?
- How often user get error from the exhibit?
- Are visitors satisfied playing with the VR exhibit?

Exhibit management:

- How well was the device managed?
- How well was the area managed?
- How well were visitors managed when playing with the VR exhibit?
- How often do visitors need help from the staff?

And the third part was a series of open ended question which asked:

- What were the problems of using the VR device.
- What were the problems you experienced when interact with the game.
- What were the problems of exhibit management.
- What recommendations or feedback do you have.

The study also observed visitors used the VR exhibit to validate the suggestion of social interaction features and social mechanisms that support visitors to have social interaction when playing the VR exhibit, as well as observing staff support visitors and manage the exhibit. It aims to inform future designing and deployment of VR exhibits in museums.

8.3.5 Procedure

The visitors were notified that the VR exhibits were part of the research process, and that the experimenter would observe them. The experimenter informed visitors who were willing to participate in the research to sign the consent form before allowing them to join inside the experiment area. The experimenter randomly assigned them to play the first exhibit. The visitor played with the first exhibit and gave their feedback on the self-report questionnaire. After the visitor finished answering the questionnaire, they felt free to play another VR exhibit or leave the study area.

The experimenter stood around the exhibition area and observed participants playing with the VR interactive exhibit, listening to their conversation, taking some photos, and taking notes. The exhibits were installed in the museum for three weeks. The experimenter interviewed the staff who managed the VR exhibit, opening and closing the exhibit every day to find issues operating the VR exhibit.

8.4 Results

The result will provide a summary of each VR interactive exhibit from the self-report questionnaire for quantitative data. And will summarise together for the qualitative data.

8.4.1 User feedback (quantitative data)

8.4.1.1 The Camouflage VR exhibit

The Camouflage VR exhibit is a single-player VR exhibit and has a single game or a mission to do in the game. Players used one interaction to play the whole game, pressing the Grip button to select an object and use the Thumbstick for movement. The results of this session gathered data from 31 participants aged between 20-60 years old, 19 male and 12 female.

Figure 8.4 shows user responses to the Camouflage VR exhibit. The statistical results show all items of the Camouflage VR exhibit received positive evaluation (4 agree, 5 strongly agree). Participants report their acceptance of using VR technology trends as positive more than negative. 74.20% of participants felt that VR headset was easy to wear (25.81% strongly agree, and 48.369% agree). 58.06% of participants felt the VR headset was comfortable to wear (19.35% strongly agree and 38.71% agree), and 58.07% of participants rated the controller as easy to use (25.81% strongly agree and 32.26 agree).

For Content and interaction design, participants gave overall feedback on their experience for the Camouflage VR exhibit. 52.61% were satisfied playing the exhibit (22.58% strongly agree and 29.03% agree), while 38.71% gave a neutral opinion. Those who were satisfied said that they are pleased and impressed with the exhibit. Most of the participants, 41.91%, does not find any error during the experience of the exhibit. And the majority of participants, 66.67%, gave positive feedback that time to play exhibits suitable for using VR (26.67% strongly agree and 40% agree). The average number of minutes that visitors played the exhibit for was M=6.49 (SD=2.03, N=15).

About the interaction design, 70% of participants give positive feedback that the design of interaction, saying it was easy to remember how to interact with the exhibit (40% agree and 30% strongly agree), while 64.52% felt it was easy to understand how to interact with the exhibit (32.26 agree and 32.26 % strongly agree). However, the majority of participants, 41.94%, are neutral how easy the games in VR were to interact with, while 45.16% give positive feedback (25.81% agree and 29.35% strongly agree).

Regarding the exhibit management for safety and health, 61.29% gave opinions that the VR device were well managed (29.03% agree, 32.26% strongly agree), 66.67% responded that the exhibit was well managed (40.00% agree, and 26.67% strongly agree). 70.96% of participants had positive feedback that for the exhibit has managed visitors well to access the VR exhibit (35.48% agree and 35.48% strongly agree). Only 41.93% were confident that they can play with the exhibit without floor staff help (29.03% agree, and 12.90 strongly agree).

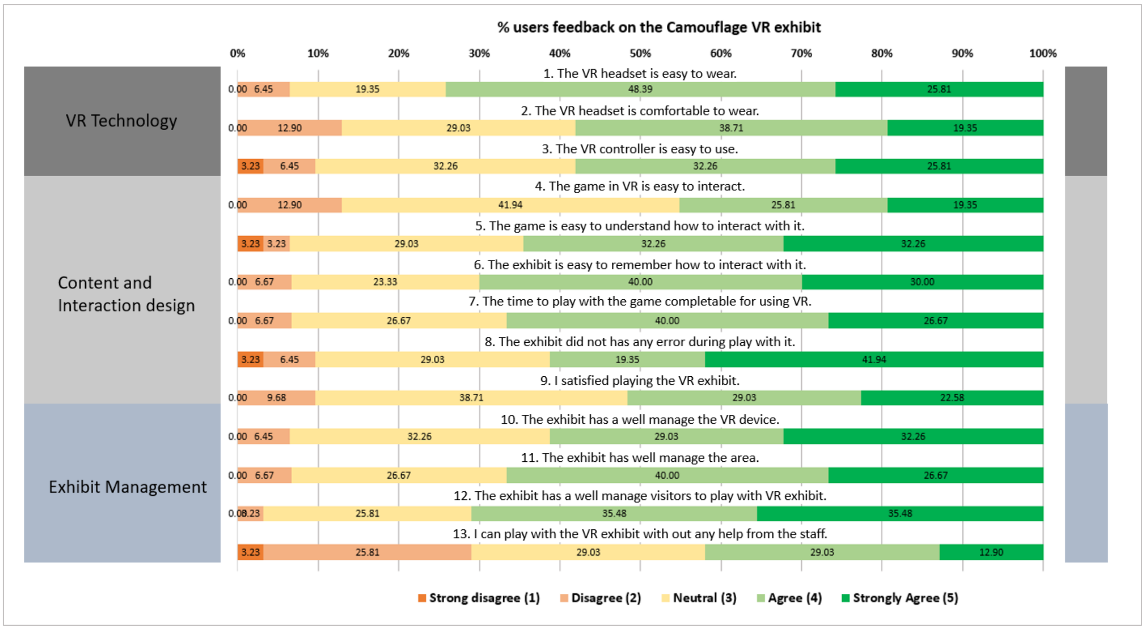


Figure 8.5 User response (as overall percentages) to the questionnaire per items of the Camouflage VR exhibit.

8.4.1.2 The Steam Engine VR Exhibit

The Steam engine VR exhibit is a multiple-player exhibit with multiple games or missions to do in the game. Players must learn how to interact with the exhibit in each game. The results of this session gathered data from 29 participants aged between 22-47 years old, 18 male and 11 female. Figure 8.6 shows user response results to the Steam engine VR exhibit. The statistical results show that all items received more positive than negative evaluations. However, some item participants' trends gave neutral feedback more than others. Overall, participants positive responded to using VR technology, 68.96% reported the VR headset was easy to wear (55.17% agree and 13.79% strongly agree), 62.07% reported the VR headset was comfortable to wear (48.28% agree and 13.79% strongly agree), 65.52% reported the VR controller was easy to use (41.38% agree and 24.14% strongly agree).

Regarding the content and interaction design and overall user experience, 44.80% give positive feedback (31.03% agree and 13.79% strongly agree), while 41.31% responded neutrally. Most participants, 51.72%, encountered no errors while playing the exhibit. Participants gave a positive opinion of 55.17% about the time to play the game suitable when using VR. The average amount of minutes players spent in the exhibit was M=9.42 (SD=5.39, N=25). 47.38% of participants responded neutrally that the exhibit was easy to remember how to interact with, while 34.48% felt positively (24.14% agree and 10.34% strongly agree). The participants gave a positive opinion that the exhibit was easy to understand how to interact with (44.83%) and 31.03% responded with neutral feedback. A large number of participants gave neutral feedback, with 41.38% expressing that the Steam engine exhibit was easy to interact with, equal to the participants giving positive feedback (34.48% agree and 6.90% strongly agree).

For exhibit management for safety and health, the Steam engine VR exhibit was rated as having good VR device management with 55.17% positive feedback, good area management with 58.62% positive feedback, and good visitor management with 62.07% positive feedback. Almost all participants responded neutrally when asked if they could play the exhibit without help from the staff, while 24.14% could play the exhibit without help from the staff.

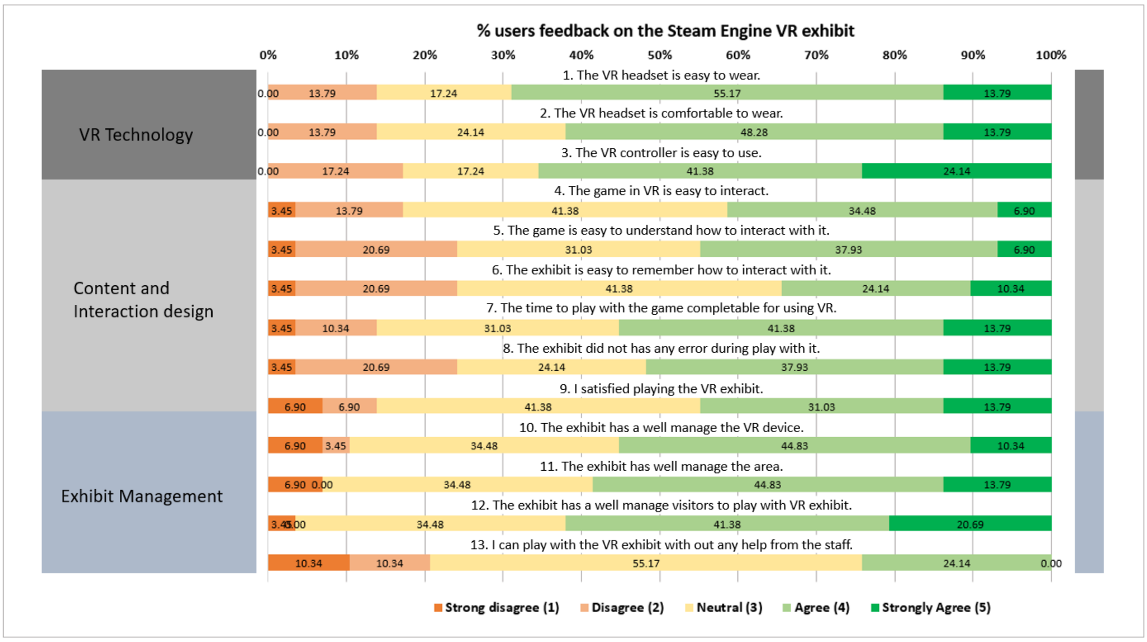


Figure 8.6 User response (as overall percentages) to the questionnaire per items of the Steam engine VR exhibit.

8.4.2 Qualitative Data

The qualitative data was collected from three sources: 1) a self-report questionnaire in open-ended questions in part 3. The feedback from the participants who played with the Camouflage VR exhibit (SR-Camo) and the Steam Engine Exhibit (SR-Steam); 2) note taking of observing visitors' behaviour and VR exhibit during the experiment in the museum (Observation); and 3) staff reports. They were converted into a text format and imported into NVivo to code and generate themes. In which the process is the same as the previous study (Section 7.4.3).

Illustrative quotes are labelled with two patterns. For the first pattern, the data gathered from participant feedback on the self-report questionnaire in part 3 was labelled with participant ID along with the ID of the exhibit that they mention. For example, (u-co-26, SR-Camo) means the data from a participant ID u-co-26 who played the Camouflage exhibit. For the second pattern, the data gathered from the observation and staff report will be labelled with the number of information and source of information. For example (V-02, Staff-Camo-03) means the information from floor staff reported running number 2 and they report for Camouflage exhibit, and specific on the participant who plays Camouflage exhibit ID 03 (u-co-03), (Ov-st-04, Observe-Steam) means the information comes from experimenter observing visitor running number 04 and observed on Steam engine exhibit but cannot specify a particular participant. The final themes are shown below:

Themes 1: Advantages of VR.

Themes 2: Concern issues caused by people unfamiliar with using new technology.

Themes 3: Concern issue cause of deployed VR devices in museums for public use.

Themes 4: Concern issue caused by System design feature for VR exhibit.

Themes 5: Role of staff for VR exhibit.

8.4.2.1 Themes1: Advantages of VR

This theme focused on how visitors feel impressed after they experience the VR exhibit. VR technology was quite new for visitors, and many reported it was their first time experiencing it. They felt impressed with VR technology (u-co-02, SR-Camo) (u-st-22, SR-Steam). The VR technology was exotic and interesting for them (u-co-20, SR-Cam) (u-co-29, SR-Cam). VR was a new media that they had never played before. It was very exciting (u-st-25, SR-Steam). The VR exhibit was very realistic (u-st-09, SR-Steam), and they enjoyed playing with the VR exhibit (u-co-26, SR-Camo) (u-st-14, SR-Camo) (u-st-05, SR-Steam).

VR is a modern and novel technology, and participants found the experience of using it very enjoyable. They enjoyed playing the game in the VR exhibit and enjoyed what they saw in the virtual environment inside the VR exhibit (u-co-07, SR-Camo). The graphics in VE were described as beautiful by u-co-12 (SR-Camo). The VR exhibit brought them into the virtual reality environment and made them feel like they were in a real game. Others felt it was an amazing virtual experience (u-co-15, SR-Camo). The VR exhibit made them understand VR technology (u-st-18, SR-Steam) and encouraged them to spend more time learning (u-co-14, SR-Camo).

Many visitors mentioned VR was easy to use and easy to understand (u-co-01, SR-Camo), (u-co-03, SR-Camo). The controller was easy to use when interacting with the game (u-co-11, SR-Camo). The software ran smoothly (game in VR exhibit) and could continuously play with the VR exhibit without any error (u-co-11, SR-Camo) (u-st-17, SR-Steam). It was clear to seen VE inside the VR exhibit (u-st-19, SR-Steam).

Many visitors gave an opinion about the benefits of VR, as follows. For example, VR could be useful and can apply in various fields (u-st-07, SR-Steam). VR is a tool that can help to create new learning media (u-st-27, SR-Steam). VR is an interesting new learning media that attracted learners' interest. VR can enhance the museum experience (u-st-08, SR-Steam). Participants suggested how VR can provide new experiences to the player. For instance, to simulate a new experience of a place that is difficult to travel to or a situation that cannot be practised in real life (u-st-13, SR-Steam), or using VR for relaxing after work by simulates a calming or desirable place such as a forest, the sea, or listening to a concert (u-co-16, SR-Camo). VR allowed players to have the experience of seeing a complicated machine and how it works, but while the simulation model is good for educating people, it would be better to add a story along with the simulation (u-st-26, SR-Steam). The VR exhibit (Steam engine) might work for teaching staff to operate the machine in manufacturing. It would be better for the museum to have a story to inspire young children and make it real, like a real machine (u-st-26, SR-Steam).

8.4.2.2 Themes 2 Concern Issues Caused by People Unfamiliar with Using New Technology.

These themes focused on subjective issues when using a new technology with which users are unfamiliar.

1) Visitors felt unconfident wearing VR headsets

The study found issues when using VR exhibits in public spaces. One from the user side: VR was quite new for users who were unfamiliar with using it and this caused issues. The experiment found many visitors had difficulty wearing the VR headset (Ov-co-09, Observe-Camo) (Ov-co-10, Observe-Camo) (Ov-co-11, Observe-Camo) (v-02, Staff-Camo) (v-05, Staff-Camo) (v-07, Staff-Camo), especially visitors who wore glasses (Ov-st-04, Observe-Steam). Many people asked if they could wear glasses while playing with the VR exhibit. Sometimes they want to try to take the glass off to play with VR, but in most cases, after taking their glasses off, they could not see the pictures inside the VE clearly.

Some participants found the HMD uncomfortable to use because of the weight, mentioning that the VR headsets were quite heavy and uncomfortable to wear (u-co-11, SR-Camo) (v-25, Staff-Camo-26). This issue was exacerbated when using VR for a long time, as they felt the VR headset was very heavy and uncomfortable for their faces (u-co-07, SR-

Camo). Participants mentioned it would be better if the VR headset was lighter than the current headset (u-co-16, SR-Camo) (u-st-07, SR-Steam) (u-st-14, SR-Steam).

2) Visitors felt confident using the VR controller

Another issue reported by some players was that they had a problem using VR controllers. Players needed help understanding how to hold the controller, and they were not confident in themselves to use the controller (v-07, Staff-Camo) (v-05, Staff-Camo). They confused the functions of the buttons on the controller (V-01, Staff-Camo) (v-04, Staff-Camo) (v-31, Staff-Camo). Players tended to explore every button on the controller and wanted to investigate what they could do with the controller even though they read the instruction before playing the game that only one button was used in the exhibit (v-08, Staff-Como). The first button that the player tried to press was the Trigger button. It was the position of the index finger. The player often used the index finger (Trigger button) to choose an object instead of the middle finger (Grip button) (Ov-co-12, Observe-Camo) (v-14, Staff-Camo). Player used their previous experience using VR to hold the controller as they had before.

3) Visitors unfamiliar to move and explore the virtual environment.

Players were unfamiliar with movement inside the virtual environment and sometimes were confused about whether to use the controller to move or walk by themselves (v-22, Staff-Camo) (Ov-co-04, Observe-Camo) (u-st-04, SR-Steam). Players did not know the red fence stationary boundary (the guardian line) and its purpose. Experiencing the virtual environment was quite new to visitors. Some participants felt nervous when walking in the virtual environment, and they felt fear of falling from a height inside the VE (u-co-16, SR-Camo). One player reported feeling very excited. After players had the experience in a short time, some players asked to take the HMD off. Other players said that the environment was very real, as if they were in the real situation. One participant who was scared of wolves felt lonely and afraid as the only one inside the virtual environment during the Camouflage game (Ov-co-08, Observe-Camo).

8.4.2.3 Themes 3: Concern Issue Cause of Deployed VR Devices in Museums for Public Use

1) Battery Consumption

VR for public spaces like the museum must be able to support many visitors each day during museum opening hours. So, it must stand by and prompt visitors to play continuously. The study found a problem with battery consumption when using VR headsets in real situations. The battery ran out quickly, even when the staff plugged the charger cable into the PC computer after each visitor finished playing the exhibit. The staff tried to find a solution to keep the battery power alive and prompt the next player to play, but the design system needed to stand by or always show the home page for the next visitor to play, causing the power to decrease quickly.

2) Signal Connection to Provide Social Interaction Feature

The system uses a wireless connection to stream content on the VR headset and displays on the PC by using the Side Quest program. The study found many delays when using Wi-Fi streaming. The people who stood around the VR exhibit were unable to follow what happens inside the VR headset while playing the exhibit (Ov-co-07, Observe-Camo). The multiplayer Steam engine exhibit experienced a problem whereby players did not join the game together simultaneously. If this happened, instead a player played on PC at the same time as the player who played in VR. Finally, as other people were unable to see what happens inside the VR headset, including the staff, who then cannot help the player solve a problem when the player suffers one in the game (Ov-st-04, Observe-Steam).

The system was designed using a Cloud Service from a third party to connect players. Sometimes the system was disconnected, so staff had to restart the system again. Resetting the system takes time, so sometimes a player would become impatient with waiting and switch to play another exhibit instead (v-03, Staff-Camo). Another issue was about the Guardian, and staff need to recreate Guardian very often as after each visitor finishes playing the exhibit, the staff would need to put the headset on the table outside the Guardian boundary.

3) Device and Area Management

The VR HMD in this study use an inside-out tracking system. The study found the Guardian of the VR system was often lost, and the staff needed to recreate it when the VR headset was put on the table where outside the guardian area. The Guardian was less often lost when putting the headset in the middle of the guardian area (Ov-addition note). The study provided an area of 2x2 square meters that provides for a player to stand inside the area during the experience with the VR exhibit. This was found to be suitable for a player to move in and was safe for the player when using the exhibit. It helped to keep distance between the player and other visitors. However, during this study, heavy crowding was not experienced to really test this aspect of the design (Ov-addition note). Figure 8.7 show examples of the device and area management.

Figure 8.7 Examples of device and area management. a)-b) are the example of the area to put the VR HMD a) put the VR HMD at the middle of guardian b) put the VR HMD on table outside the guardian. c)-e) are an example of player movement inside the play area 2x2 square meter. c) using wireless stream content display on PC. d) using wire connection to stream content display on PC. e) show another visitor keep distance from player which stand outside the play area.

8.4.2.4 Themes 4: Concern Issue Caused by System Design Feature for VR exhibit.

1) System structure: participants reported that they enjoyed playing with the exhibit's (u-co-07, SR-Camo). Some participants wanted the game to be more playable (u-co-09, SR-Camo) and wanted to have a wider variety of games in one VR exhibit (u-st-09, SR-Steam). However, the study found that a single game and less variety of interaction design allowed participants to perform the exhibit's task better than having many games and multitasking in one VR exhibit. A variety of games causes players difficulty when playing with the exhibit at the first time. For example, the Steam engine game design for the VR exhibit has many tasks in one game. It was found very often that players asked staff how to play when the game changed to the next mode, especially for completing a mission task in the game, as players did not understand how to deal with the new mission (Ov-st-17, Observe-Steam) (v-17, Staff-Steam-17), so staff helped the player to play the game (v-11, Staff-Steam) (v-12, Staff-Steam) (v-32, Steam-27).

2) Instruction: instruction was essential to tell visitors how to interact with the system, especially for people learning to use new technology and play with a new exhibit. Usually, the instructions would be displayed before the player plays the game. From observation, some visitors needed help remembering the function of each button on the controller and their task (Ov-st-12, Observe-Steam) (Ov-st-16, Observe-Steam). The instructions should show or guide the player to play again during their play exhibit (staff recommendation).

VR exhibits in this study were adapted from the experiments for run study two and study three. The study found that the exhibit needs more explanation on how to play the exhibit when using the exhibit beyond the lab experiment. The instruction should include the exhibit's purpose (u-st-21, SR-Steam), how to play and clear (u-st-01, SR-Steam).

3) Automatic Reset system for VR exhibit: the reset system design for each exhibit automatically goes back to the home page as suggested in the proposed framework. The floor staff reported that it helped them to manage the VR exhibit prompt for the next player. The reset system and hidden function to activate the Home page button enabled staff to reset the system when they had a problem. And staff reported it did not disturb visitors who experienced the exhibit.

4) Design feature that stimulate motion sickness: using VR can cause stimulation motion sickness and this study found that some visitors felt dizzy after playing with the exhibit. It occurred more often with the Camouflage exhibit than the Steam engine exhibit. Some visitors felt a little dizzy (u-st-01, SR-Steam) (Ov-co-18, Observe-Camo), and some visitors, after they felt dizzy, stopped and took the headset off (Ov-co-10, Observe-Camo) (v-09, Staff-Camo) (v-13, Staff-Camo) (v-20, Staff-Camo-23) (v-30, Staff-Camo-30) (v-31, Staff-Camo-31) (v-33, Staff-Steam-28) (v-34, Staff-Steam-29).

Many factors stimulated motion sickness in this study. Players felt dizzy after playing with VR because they felt uncomfortable wearing the VR headset, and during play inside the VE, and they had to move around often, making them feel dizzy (u-st-02, SR-Steam). One participant reported to staff that they felt dizzy after playing the VR exhibit because the movement inside the VE of the headset did not synchronise with player movement (Ov-co-23, Observe-Camo) (v-09, Staff-Steam). One player reported that he was very sensitive about motion sickness. He often felt dizzy when watching moving pictures, playing an first person shooting (FPS) game, or watching a movie in the 360-degree dome. They felt dizziness after playing with VR made some players feel they did not want to use VR again (u-st-25, SR-Steam). It was very often found that players stand unstable when during wear VR, as if they were wobbly.

8.4.2.5 Themes 5: Role of Staff for VR Exhibit

VR technology was quite new for the visitors. The floor staff was necessary to deal with new technology and provide visitor support. Many participants reported that they received help from the staff (u-co-06, SR-Camo) (u-co-21, SR-Camo) (u-st-06, SR-Camo). Staff explained how to play with the exhibit to players and answered questions when players suffered problems during play (Ov-co-03, Observe-Camo) (Ov-co-05, Observe-Camo) (Ov-st-10, Observe-Steam).

Floor staff helped visitors access the VR exhibit. First, they helped visitors put on the VR headsets and use a VR controller. They also provided safety to the player during play with the VR exhibit, such as telling other visitors not to get inside the play area and offering help when some players felt dizzy during or after play with the VR exhibit. Floor staff helped manage waiting queues, allowing visitors to play with the VR exhibit.

Floor staff helped to manage the VR headset and system. As the VR headsets often ran out of battery, the staff needed to recharge it often over a day, indicating that the setup of the exhibit—connecting the signal and providing power to the VR headset, needed to be better. The floor staff had to clean the headset before other players used it. The floor staff also helped monitor the system to connect properly, and all the data was synced and displayed on the PC screen.

Figure 8.8 Staffs help visitors wear VR HMD and teach them use the controller.

8.5 Discussion

This section will discuss the success of validating the proposed framework with an in-the-wild study, and any concerning issues for each component of the design will be discussed.

8.5.1.1 Content Design Component

The content design of the Camouflage VR exhibit applied gamification design with a role play interaction style. The Steam Engine VR exhibit had four interaction styles: exploration, quiz, explanation, and completion. The exhibit succeeded, and participants reported they felt impressed, entertained and felt excited playing the games in the exhibit. The statistical result showed users were satisfied using the VR exhibit. Only 9.63% of the Steam Engine and 13.8% of the Camouflage users responded with negative feedback, even though they sometimes did encounter some problems during the experience with the exhibit.

This study deployed VR exhibits in the museums and the factors of Content design did not show any incompatible to provide visitors experiencing the VR exhibit. In addition, the study found suggestion issues to concern when designing the content of VR exhibits as follow:

1) The complexity of the task and interaction pattern affected the player's understanding of how to interact with the exhibit: when designing games for VR exhibits a designer should consider between creating a single task or multiple tasks. The experiment found that players tend to have more problems when the exhibit has a variety of tasks in one VR exhibit, such as the Steam Engine VR exhibit. For example, the Steam engine exhibit had four tasks to do in one exhibit, and each task had its own design for interacting with objects in the VE. When designing multiple tasks in one exhibit, players must take time to understand how to interact with each task. For a single task, players can get familiar with and interact with the game easier. Therefore, when designing a game for an exhibit, one should balance between providing a variety of interactions in one game for the player and the time that the player try understands how to interact with the game. However, designing a game with a single action in-game lets the player easily and quickly understand how to interact with the game, although it might risk the player feel bored playing it more quickly.

2) Having many games in one VR exhibit increases the duration spent using the exhibit: some players felt the headset became very heavy or uncomfortable when they wore it for a long time. Given this, the content design should consider how long the player will take to finish the experience with the exhibit. The time consumption using the VR headset also impacts queue length for visitor access to the VR exhibit. Choosing the Interaction Style, a number of modes and creating a Narrative story are all related to estimating the time that players will spend in the exhibit.

8.5.1.2 Action Design Component

The interaction design of the exhibits uses controller action as the input. The Camouflage used a laser pointer and click to select an object. The Steam engine used a laser pointer and click to select an object, and use pointer drag and drop an object. Overall participants felt it was easy to use the controller. The interaction design was quite successfully as participants agreed on average that it easy to interact with the. Only 17.24% of the Steam Engine exhibit and 12.9% of the Camouflage exhibit disagreed that the game was easy to interact with. The were also a number of participants who gave neutral feedback. One reason that made some the participants had difficulty interacting with the VR exhibit was unfamiliarity with moving in the virtual environment. They felt confused between walking and using controller. This result indicated that choosing Navigation factor of the Action Design component is important and must be trained and communicated clearly.

Players found it easy to understand and remember how to interact with the VR exhibit with single pattern of interaction design more than multiple patterns of interaction design. This resulted in participants giving positive feedback to interaction design of the Camouflage exhibit more often than the Steam engine exhibit, in which the Steam engine exhibit have multi pattern of interaction in the game; Steam engine was felt to be easy to understand by 44.83% and Camouflage 64.52%, while Steam engine was reported as easy to remember by 34.48% and Camouflage 70.00%.

The controller mapping factor of the Action Design component is another factor that affects user experience. Controller mapping considers the design of controller functionality and how input and feedback is performed by the device [26]. A prior study found that the controller scheme design (the control-display mapping to a given interaction technique) influences user experience in performing tasks in the game, and they discussed that familiarity with previously using controller schemes affects how intuitive the controls felt for a player [136]. Another study argues that unfamiliarity with using advanced control technology decreased players' enjoyment of playing games [123]. Using one button for interacting with objects was recommended to minimize the complexity of design controller schemes [141]. However, selecting the right button is essential to make it easier for the player to use the controller. Following this study the researchers point of view is that, when designing controller schemes or mapping button functions and interaction for the game, one should use the common function or purpose that the manufacturing technology defines default function for each button. This makes people familiar with how to interact with the exhibit.

A suggestion to design the mapping function of the controller is that due to the limitation of human fingers, the thumb and index fingers provide the optimal ability to use the controller. They should be designed for primary control. Fitt's Law refers to the distance and width of the target object being related to the time to move and access the object [203], and should also be considered. The moving time will be less if the target objects are short distances away and larger. To apply both basic principles, knowledge of design controller layout is that placing buttons closer and with a bigger size will result in more physical accessibility. Prior work recommends one should design the most frequent place on the game controller to match the primary control of the game, which is the positioning of the index finger and thumb [48].

And another aspect to consider when using the commercial controller in the museum for public use is how to prevent the player from accessing other buttons which will activate the system function. It will cause the player to be confused during play with the exhibit. It might also cause a problem in bringing the player to another point of the system.

One solution that might enhance the learning potential of the user during exhibit use is to use the system is that improve the efficiency by offering instruction to the player. One study found that the tutorial modality influences learnability using a controller. Using a tutorial by creating a tooltips which highlights and labels buttons on the controller offered higher performance than using a diagram and text [101]. Another study found that using a just-in-time tutorial performs better than a traditional tutorial that provides all instructions on one screen at the beginning before starting the game [63].

8.5.1.3 Social Interaction Design Component

This study showed that VR exhibits succeed in supporting social interaction between visitors. Social features and social mechanics design for the exhibit allow visitors to communicate. It also found VR systems can connect player by using a mix between symmetric connection and asymmetric connection, giving the benefit of supporting learning with sociocultural learning, which enables co-presence, co-player, and competition design. Figure 8.10 show examples of social interaction between players, showing an example of social interaction using mixed symmetric and asymmetric connection, and showing visitors using social interaction features and social mechanisms to experience the Steam engine exhibit.

The design feature of the social interaction supports visitors to communicate and interact with each other when playing the exhibit. The study also confirms that using asymmetric connections of social interaction design connection players is helpful for VR exhibits. This study found that visitors and floor staff use PC for various purposes, as follows:

First, visitors who come together use a PC to play with the people in their family and can interact which each other in the game. For example, even though the study did not allow their children to play with VR, the mother uses a PC to show them what their father is playing in the game.

Second, the staff uses a PC to access the game with the visitor who did not have a partner to play the game, and the staff uses a PC to monitor the player playing the game inside the VR headset. When the player suffers some problem in the game, the staff can use the PC to help the player or explain how to solve the problem in the game.

Third, use the PC to stream content from the VR headset so that other visitors who stand around the VR exhibit can see what happens inside the VR exhibit.

However, the study found that when connecting a PC for multiplayer exhibits, such as the Steam engine VR exhibit, the content on the PC did not follow what happens inside the VR when only one player plays the game using VR and no one plays the PC. Thus, visitors who stood around watching did not know what was happening inside the VR; the co-presence of the VR exhibit is lost in this scenario. Therefore, designing the multiplayer exhibit should provide a way to show the VR content on the PC and what happens inside the VR in this case. In another direction, the Camouflage VR exhibit is a single-player game. The system was set up only to stream content from the VR headset for display on the PC screen. It allows other visitors to see what happens with the exhibit. The study found that when the player suffered some problem in the game, the staff could not help or guide them to solve the problem. It is the disadvantage of setup a single player with streaming content from VR to PC.

Figure 8.9 shows a scenario of visitors playing the VR exhibit. In case 1, the exhibit has two players; one using a PC and another using a VR HMD. In case 2, the exhibit has only one player using VR HMD. In case 3, the exhibit has two players using VR HMD. Case 2 and case 3 should consider how to display the exhibit’s content on a PC which can set a co-presence situation that mirrors content from a VR HMD. Or set a co-player situation that allows another visitor or staff to interact with the exhibit.

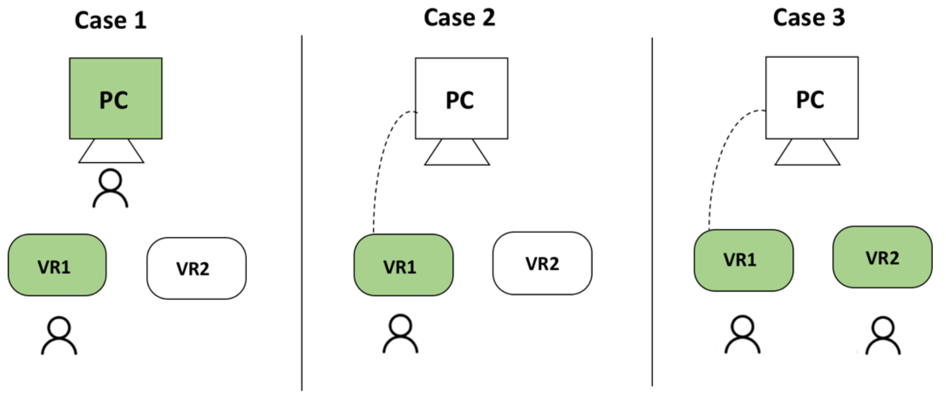


Figure 8.9 The scenario of visitors plays the VR exhibit when use both symmetric and asymmetric connection.

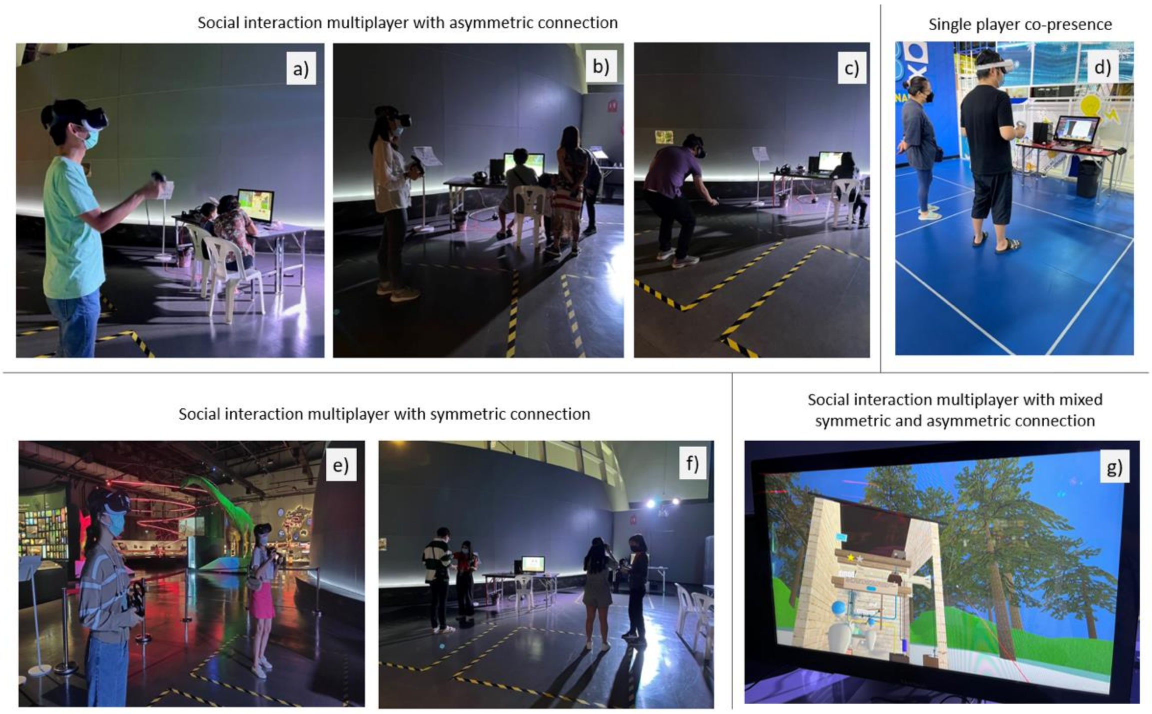


Figure 8.10 The example of social interaction among visitors during interact with the exhibits. a)-c) An example of social interaction of multiplayer with asymmetric connection. d)-e) An example of social interaction

8.5.1.4 System Design Component

The VR exhibit success in term of system design. The reset system feature is a factor of the System Design component that helped the staff to manage the VR exhibit. The staff reported the reset system: static home button, dynamic home button, and auto reset, supporting them to setting up the game prompt for the next visitor to use or in case they have a problem. The statistical result shows participants reported got some error during play in the exhibit in which the Steam engine reported an error of 13.80% and the Camouflage reported an error of 9.68%, which the accident error is the uncontrolled situation such as connection signal.

The System Structure factor of the System Design component is one factor of concern when designing the VR system. This study shows that the complexity of the design system causes the users to have difficulty understanding and remembering how to interact with the exhibit. The System Structure factor allows designers to think about how the system they design, simple or complex, will affect user experience and time visitors using the exhibit. The VR HMD device also affects the system performance in this study. When choosing the VR HMD, one must signal loss and power consumption. The tracking system in this study found a concerning factor with guardian loss, which uses an inside-out tracking system. And it relates to putting the VR HMD inside or outside the guardian. Putting the HMD outside the guardian trend increases the loss of the guardian, requiring the system to be set up again by staff.

8.5.1.5 Safety and Health

The exhibit succeeded in terms of well manage devices, areas, and visitors to access the exhibits. It supported visitors' convenient and safe access to the VR exhibit. The statistical result shows that most participants gave positive feedback that the management of the device, area and visitors. The study shows more than half of the participants had never used VR technology before. They needed the staff to support them to play with the exhibit. 24.14% of the participants reported can play the exhibit Steam engine without help from the staff, 41.93%. for the Camouflage exhibit. If the exhibit is more complicated to play it needs more support from staff.

The staff supported organising the VR exhibits, such as helping visitors access the device, helping solve the problem, guiding visitors to play the exhibit, and offering help when players feel dizzy. The floor staff helped manage the queue to allow other players to play and monitor players wearing and playing VR, such as watching other visitors not get into the play area. Design the ability to stream content to display on a PC with a Wi-Fi connection provides more comfort to the player playing with the exhibit. Still, due to the battery consumption of the headset, staff need to manage and recharge it every often. Furthermore it can be quite challenging for developers to develop multiplayer VR to run smoothly due to connection signals and managed both players into the scene together simultaneously. The staff must also help to deal with this situation.

Safety and health components help the designer consider factors when deploying the VR exhibit in the museum setting. The results from this study show the relation of some factors, such as the problem of guardian loss related to managing the device where the area to put the device, inside or outside the guardian.

8.6 Conclusion

This study intended to evaluate the proposed framework in the museum setting to validate that components of said framework are valid and capable of being used to guide the design of a new VR exhibit. Specifically, it evaluated the System Design and Safety and Health components when deployed inside the museum. The study adjusted the VR exhibits from the previous study according to the proposed framework suggestion. The exhibit from Study two is the Steam engine VR exhibit, an example of multiplayer enabled for co-player and co-presence. The exhibit from Study three is Camouflage, an example of single-player co-presence. The Steam engine exhibit had multiple tasks (game), and the Camouflage exhibit had a single task (game). The VR exhibits were displayed in the museums for three weeks to collect the data.

The study used qualitative and quantitative to validate the framework through the VR exhibit by gathering user experience using the VR exhibit. The quantitative data was recorded via user feedback on a self-report questionnaire. The qualitative used an observational study to observe participants interact with the exhibit and observe staff managing the exhibits to investigate issues to further inform the framework. The Camouflage exhibit had 31 participants join the study, and the Steam engine had 29 participants join the study.

The results from this study show that the overall user experience after the participant played the exhibit was more positive than negative, and users were satisfied playing the VR exhibit. Users felt excited, enjoyed and impressed experiencing the VR exhibits. The majority of participants were satisfied after playing with the exhibits. Participants had more positive responses that the VR exhibits are easy to interact with, understand, and remember how to interact with. The results show that the VR exhibit's social interaction feature and social mechanics supported visitors to have social interaction and communicate. The reset system back to the home page of the exhibit helped staff manage the exhibit prompt for the next visitor to play. The result shows the VR exhibit had well-managed VR devices, areas, and visitors. The result shows each factor of each component related to the design of the VR exhibit that affects user experience should be considered, as mentioned in the discussion section. These show that the suggested framework of components and factors for designing a new VR exhibit is sufficient, given participants' positive response to the VR exhibits after they experienced it.

The results from this study suggested points to consider when designing exhibit use in the museum setting as follows. The design function of each button on the controller and interaction should consider both familiarity and ease of using the controller. It should keep standard or normative design functions and interactions with other products in the same technology category to help players to quickly and easily understand how to interact with the system. The complexity of the task and interaction pattern affect the user's experience of learning how to interact with an exhibit. A long narrative or design paradigm of many games in one VR exhibit impact time consumption to play the exhibit, which in turn can lead to player discomfort. The more complex the exhibit, the more staff are required to facilitate visitors and manage the VR exhibit. One should consider when designing a VR exhibit how to support co-presence social interaction by streaming content from a VR to display on a PC, which enables staff to help visitors. And when designing asymmetric connections without the visitor playing the PC, one should to find a mechanism that can display content on the PC from VR HMD.

Chapter 9 Proposed Framework Evaluation

9.1 Introduction

After the preliminary proposed framework is created, the next step is to evaluate how the proposed framework helps and facilitates the museum to create a new VR interactive exhibit [11, 144]. This step also provides feedback to improve the proposed framework. This chapter will describe the concept and the steps to evaluate the framework.

This chapter starts with section 9.2, outlining the goals of this study. Next, section 9.3 explains this study's design, including the proposed framework format, participants, measurement, and procedure. Section 9.4 reports the results found from this study, both quantitative and qualitative. Next, section 9.5 discusses the interpretation of what this experiment found. Lastly, section 9.6 summarises the information of this study.

9.2 Study Goals

The study aims to evaluate the proposed framework, which focuses on

1) Does the proposed framework have the efficiency to help the designers design a new VR exhibit?
2) Are the components of the framework appropriately chosen?
3) How does the proposed framework help designers design the VR exhibit?

9.3 Study Design

9.3.1 Proposed Framework Format

The proposed framework was designed as a worksheet interface (layout) for participants in the workshop. The proposed framework has two formats: paper-based and online form. Both formats keep the same layout, as much as possible given constraints of the online tool. The online format used the ZOHO form to create the proposed framework form. Figure 9.1 shows an example of the online format, and Figure 9.2 shows an example of the paper-based format.

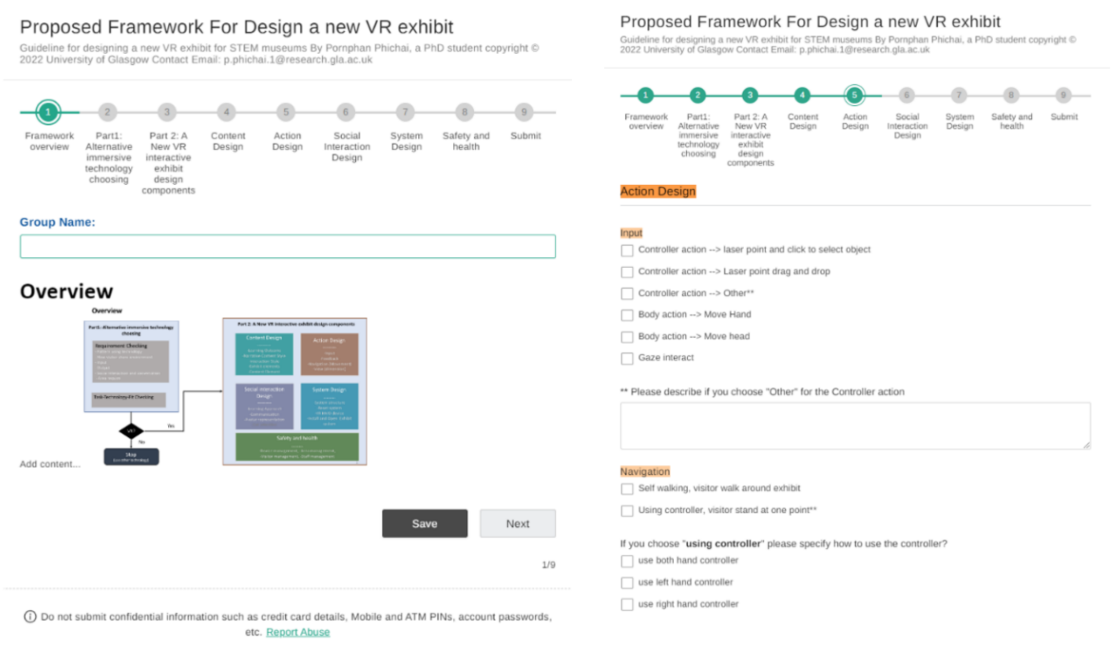


Figure 9.1 Example of the proposed framework online format.

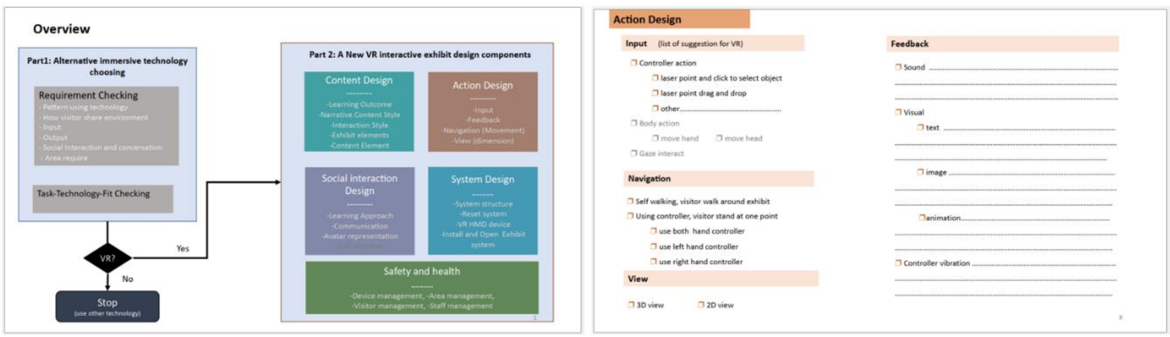


Figure 9.2 Example of the proposed framework paper-based format.

9.3.2 Participants

Participants for the workshop are targeted based on their ability to evaluate the framework. It needs to be assessed by people who have expertise and experience in exhibit design and exhibition design, by science educators, exhibit developers and Unity C# developers working for the museums. The NSM Thailand sent an official letter inviting other museums to participate in the workshop via email. Three museums accepted the invitation and assigned their staff to join the workshop online. The three museums include the Shanghai Science & Technology Museum (SSTM), National Science and Technology Taiwan (NSTM), and Miraikan -The National Museum of Emerging Science and Innovation Japan.

The NSM Thailand also circulated a memo inviting the head of each division to select their staff to participate in the workshop onsite.

The workshop was conducted two times, onsite and online. The onsite workshop included 16 participants and 2 participants with Unity and VR experience development expertise. The online workshop included 7 participants, 1 participant who has expertise in Unity development, and 5 participants who joined the workshop for observation and were not involved in discussion or group work (these were leaders and the director of the museum). The result shown in this section will report from 23 participants (16 onsite and 7 online) who fully joined the process in the workshop. They are museum staff from 4 organizations.

9.3.2.1 Participant Demographics

The participants have ages around 27- 48 years, 15 are male, 7 are female and 1 is non gender. The participants have skills working for a museum with an average of 8.381 years' experience (max=20, min=1, N=22). In addition, the participants reported that their expertise about the museum includes: exhibit designers (9 people), science educators (9 people), software developers (1 person), and other experts (4 people). In addition, the participants reported their roles and responsibilities in their museum: 6 people who designed and developed exhibits; 5 people who designed, developed, and delivered science activities; 4 people who are researchers, managed collections and archives, and delivered science knowledge; 2 people who conduct education research and develop programs; 2 people who conduct electronic and software development for an exhibit; 2 people who conduct maintenance and take care of circular exhibitions; and one person who is a science educator supporting education and exhibitions. Figure 9.3 show the participants' background information.

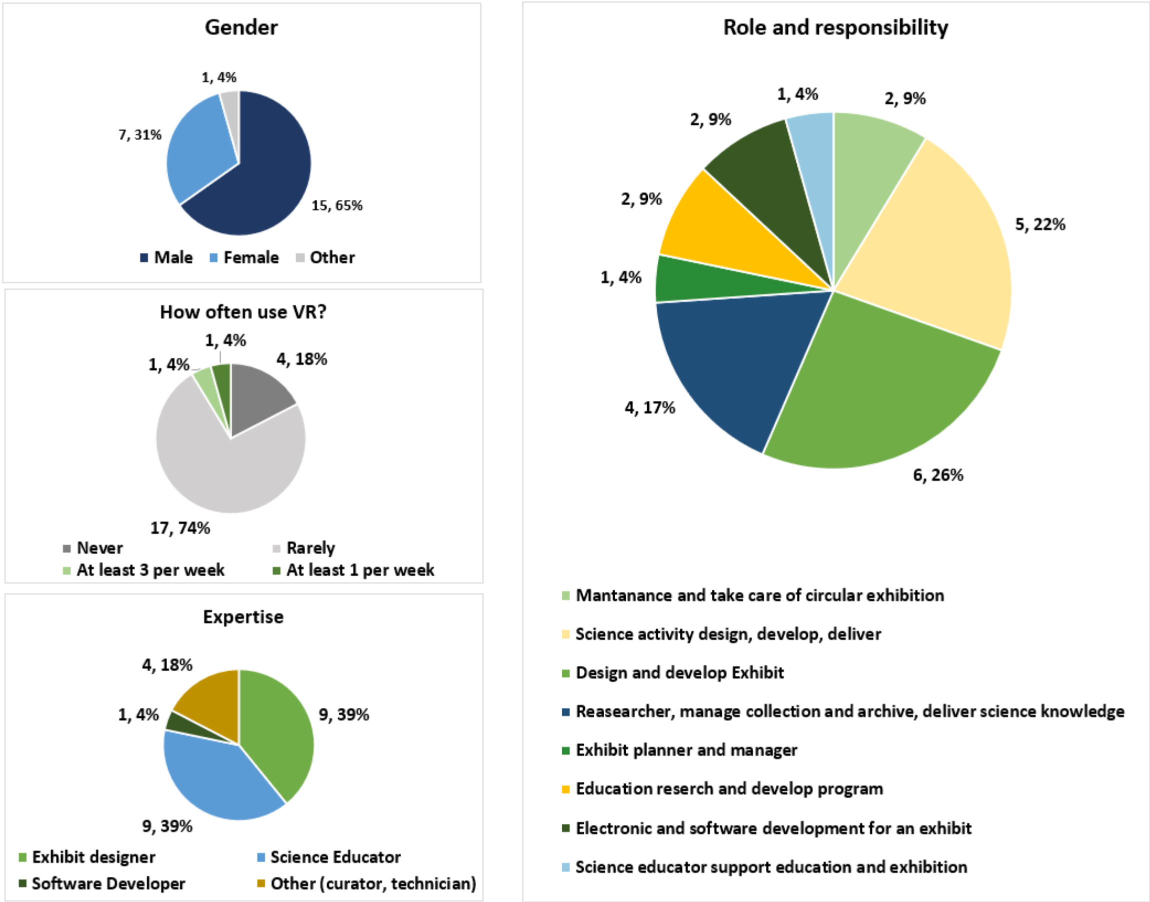


Figure 9.3 Participants' background information.

9.3.3 Measurement

The study uses both quantitative and qualitative data to evaluate the Framework. The quantitative data gathering is from the user feedback in the self-report questionnaire.

The specific aim of the Framework is to help the museum create a new VR exhibit and help to plan to design essential components of the VR exhibit which support social interaction, and to reduce the risk of failure when creating a new interactive exhibit. The Framework's output indicator consist of helping to choose immersive technology to create a new interactive exhibit; helping to design content, action, social interaction, and the system design for the new interactive exhibit; helping to manage exhibits when used in the actual exhibitions; and determining if every component in the Framework is appropriate for the given design. The study used a questionnaire that included three parts: 1) pre-workshop part 1: user background experience, 2) post-workshop part 2: user satisfaction feedback, and 3) part 3: other recommendations. Part 1 and Part 3 use open-ended questions to gather user opinions. Part 2: user satisfaction self-reports with five scales (from -2, strongly disagree, to +2, strongly agree). The questionnaire was translated from English to Thai, and the Thai language was written next to each English question to help Thai participants understand the questions. The Appendix F show the questionnaire of this study.

9.3.4 Procedure

The process to evaluate the proposed framework consists of three phases: pre-workshop, workshop day, and post-workshop.

Pre-workshop, each participant was asked to join a special online seminar conducted by the research team (research, supervisors, NSM Thailand). The topic of the special seminar is What's the metaverse? How VR and immersive technology can be powerful tools for museums? Associate Professor Dr Julie William was the invited guest speaker to deliver the talk. The special seminar took one and a half hours via Zoom. At the end of the seminar participants were allowed to ask questions. The seminar was open and the public was able to join the seminar. The seminar aimed to prepare participants with a knowledge background of VR and immersive technology and ideas for creating VR projects.

The workshop day: the workshop was conducted two times, once onsite and once online. The onsite workshop lasted one day and was held at NSM Thailand. The invitation letter was sent to each division in the NSM organisation. The director of each division chose staffs whose abilities matched the requirements (participant requirement criteria). On the workshop day, the participants were divided into four groups. The online workshop was conducted via Zoom, with participants from the four organisations mentioned in section 9.3.2 divided into three groups. The schedule was divided into two days due to the time difference between countries. The process of the workshop as follows:

1) Ask the participants to do the pre-workshop questionnaire. The questionnaire has questions that wants to access their background information and experience in designing an exhibit for the museum. It also asks them to prepare some data about the exhibit that they want to create in the workshop.

2) The workshop was conducted in the conference room of NSM. The participants were divided into groups. Each group was provided a PC and VR Oculus HMD. Case studies that use VR were also set up inside the room. The workshop invited two experts to join the

workshop to facilitate participants for VR and Unity development. One was a manager of a company that has a service to develop VR experience applications, and another was an IT expert and Unity game developer working under the Ministry of Higher Education, Science, Research and Innovation. The workshop was divided into nine sections, table 9.1 described each section.

Table 9.1 The detail of each section in the workshop.

Section	Detail
Section 1	Opening remark and introduce the workshop.
Section 2	Giving background information about VR and immersive technology.
Section 3	Introduce how to use the proposed framework to develop a new VR exhibit.
Section 4	Allow participants to get familiar with using VR headsets and have an experience with the example VR exhibit.
Section 5	Working in a group, practise using the framework to design a new VR exhibit. Each group brainstormed to generate the conceptual idea for a new VR exhibit. The researcher provided them with a worksheet for practice using the proposed framework to design the new exhibit (using the proposed framework part 1).
Section 6	Each group had a short presentation of the new VR exhibit's conceptual idea, including the topic of scientific content and how visitors interact with the new exhibit.
Section 7	Testing the compatibility of interaction and the VR technology. In this step, each group examines the technology used to implement the interaction that they want visitors to have with the new exhibit (using the proposed framework part 1 TTF check). They can check the interaction compatibility in two ways. First, actual coding that technique in Unity to check that their conceptual idea can be precise. Second, they asked the expert how to do this and the expert explained and provided an example. Also, participants were able to search for an example of interaction technique online.
Section 8	Iteration, in case the first interaction part failed, and they cannot find a technique to implement the interaction precisely. If they complete the design exhibit in part 1 of the framework, then they continue to design the detail of the exhibit (proposed framework part 2).

Section	Detail
Section 9	Present the new VR exhibit. After each group finished designing the details of the exhibit, following the proposed framework guideline (fill in the information in the framework), they presented their ideas for creating the new VR interactive exhibit. The presentation prompts all the participants to ask questions and discuss with the presenters.
Post workshop	
Section 10	Framework evaluation and feedback. Participants were asked to complete the post-workshop questionnaire and get feedback from them to improve the proposed framework. At the end of the workshop, questionnaires were examined to discuss issues and give opinions on using the framework verbally. The experimenter recorded a video during the workshop and recorded voices during group discussions and interviews. The onsite workshop was run in Thai, and the results were translated into English. The online workshop ran in the English language.

Figure 9.4 show the example of the process of the workshop. Picture a), b), and c) show the onsite workshop. Picture d), e), and f) show the online workshop. Picture a) The researcher gives an overview and explains how to use the Framework. Picture b) A group of participants present an idea for the new VR exhibit. Picture c) Participants experience examples of the VR exhibits. Picture d) A group of participants present an idea for the new VR exhibit online via Zoom. Picture e) A group of participants present the flowchart of the design of the System Structure of VR exhibit. Picture f) The researcher demonstrates the examples of the VR exhibits.

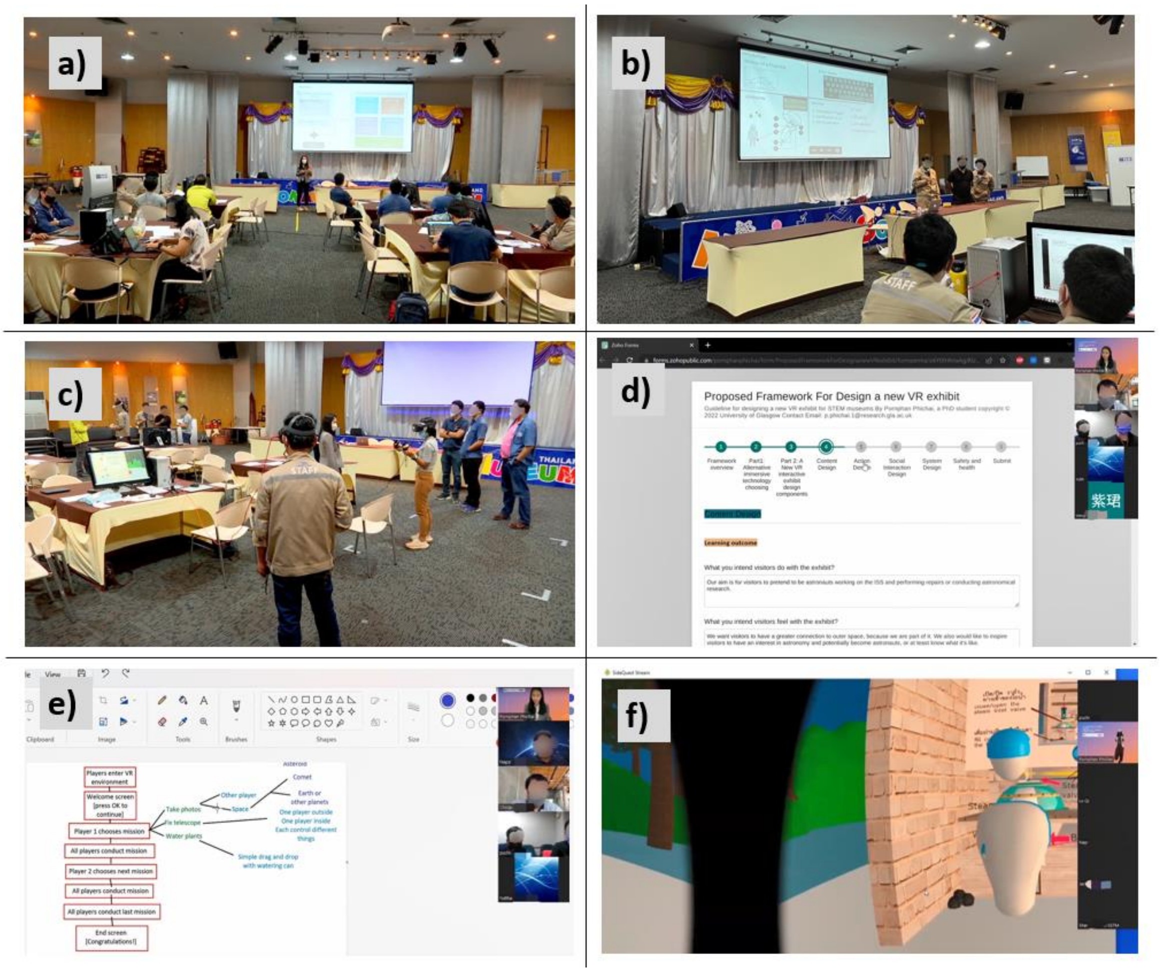


Figure 9.4 The example of process in the workshop, onsite and online. a) The onsite workshop introduces an overview of the framework. b) Each group present their design for a new VR exhibit. c) The case study of a VR exhibit is demonstrated, and participants are allowed experience it. d) Online workshop, each group presents their design of a new VR exhibit via Zoom. e) Online workshop, a group use Pain software to illustrate their System Structure Design. f) Online workshop, demonstrate a case study of VR exhibit via Zoom.

9.4 Results

9.4.1 User Feedback (quantitative data)

Overall, participants responded positively to the idea of using the framework to design a new VR interactive exhibit. All the components in the framework received positive feedback. It helps to design a new VR exhibit; the component of the framework is appropriate in design, and the support information along with using the framework is appropriate. The results found that almost participants gave positive feedback in the evaluation. However, it found two participants gave negative feedback on all items in the questionnaire, which contrasts with the majority of participants in this study. The detail of the results of the evaluation are described below:

9.4.1.1 Overall Results of Part I and Part II

Figure 9.5 show the overall of user feedback. The results of the overall evaluation of framework Part 1 shows that 39.13 % strongly agree and 39.13 % agree that Part 1 of the proposed framework is helpful to choose technology. The result shows that the component of part 1 had an appropriate design, which received 78.26 % positive feedback (43.478 % agree, and 34.783% strongly agree). And the result indicated that the component of part 2 (Content Design, Action Design, Social Interaction Design, System Design, Safety and Health) had the appropriate design, which received 78.26% positive feedback (47.826 % agree, and 30.435 % strongly agree). The information support using the framework received a positive evaluation, it is helpful 47.826 % agree, and 30.435% strongly agree.

9.4.1.2 Content Design

The Content Design component received positive feedback. It is helpful to help design the exhibit’s content with 47.82% agreeing and 34.78% strongly agreeing. The result shows that elements of the Content Design component are appropriate, with 39.13% agreeing and 30.43% strongly agreeing. The information support provided to help designers design content received positive feedback, with 39.13% agreeing and 39.13% strongly agreeing it is helpful.

9.4.1.3 Action Design

The Action Design component received positive feedback 47.82% agree, and 34.78% strongly agree that the Action Design component is helpful to design the interaction of the exhibit. When asked if the Action Design component element is appropriate, 39.13% of participants agree and 34.78% strongly agree that they are appropriate. The support information helps the designers design an exhibit interaction, in which 47.8% agree, and 26.08% strongly agree.

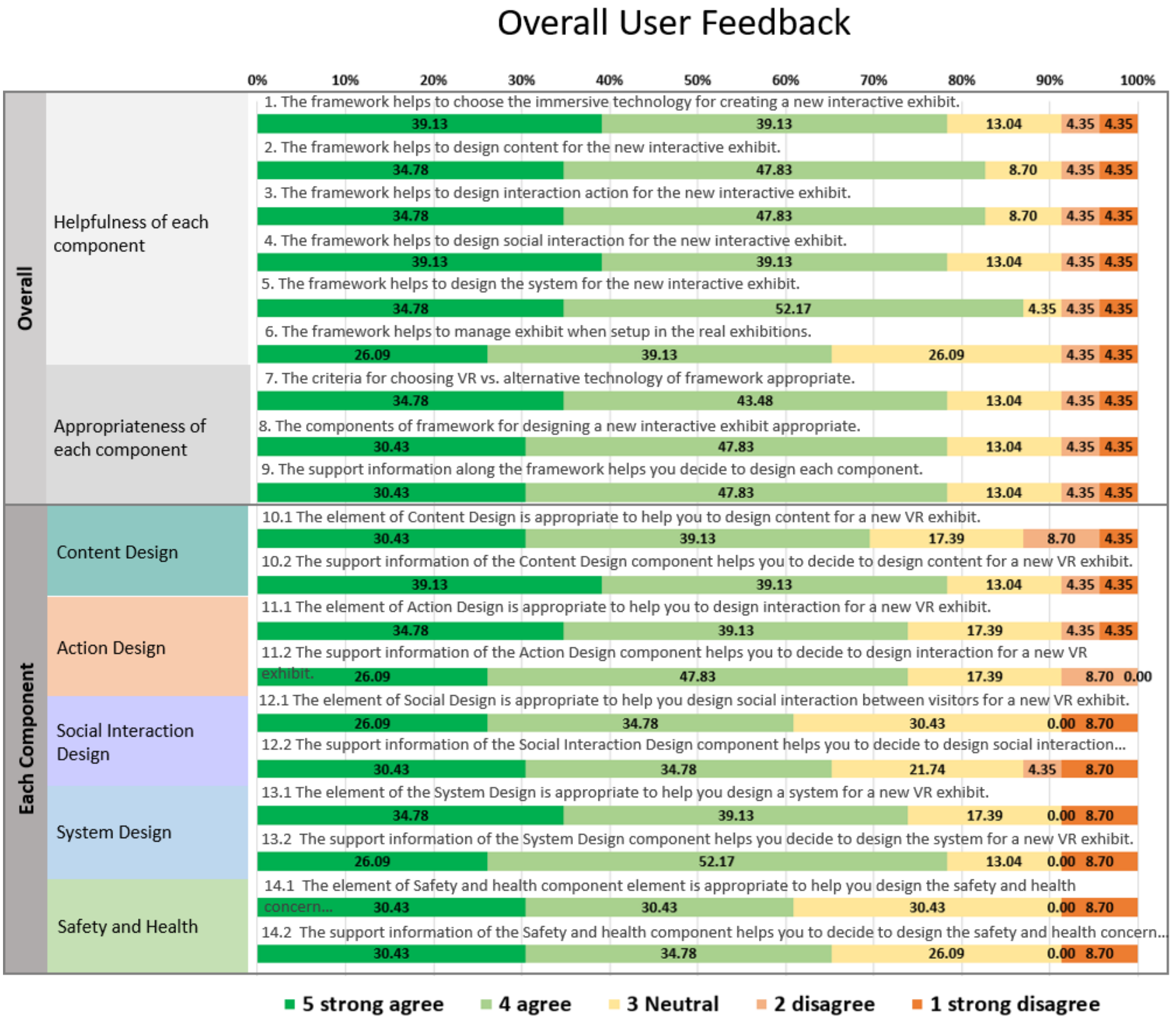


Figure 9.5 The stacked bar of Overall User Feedback.

9.4.1.4 Social Interaction Design

The result shows that the Social Interaction Design component received positive feedback evaluation from participants, 39.13% agree and 39.13% strongly agree with the statement that the Social Interaction Design component is helpful to the designer when designing social interaction. The element of the Social Interaction Design component is appropriate, of which 34.78% agree, and 26.087% strongly agree. When asked if the support information is useful to help design social interaction, 34.78% to agreed, and 30.43% strongly agreed.

9.4.1.5 System Design

The result shows that the System Design component is helpful in helping the designer design system of an exhibit. It received positive feedback, of which 52.17% agree, and 34.78% strongly agree. The element of the System Design component is appropriate (39.13% agree and 34.78% strongly agree). The support information is helpful to support designers in designing a VR exhibit system, of which 52.17% agree, and 26.08% strongly agree.

9.4.1.6 Safety and Health

The Safety and Health component got a positive evaluation. 39.13% of participants agree and 26.08% strongly agree that it is helpful to help the designers concerning the safety and health while using the exhibit. The result show that the elements of the Safety and Health is proper in design, with 30.43% agreeing and 30.43% strongly agreeing. However, 30% of participants gave neutral feedback. The support information to design safety and health got the positive feedback which 34.78% agree and 30.43% strongly agree.

9.4.2 Qualitative Data (user opinion, workshop observation)

The results in this section report data from 1) Open ended answers from the questionnaire, 2) The worksheet for practice using the framework, 3) Note taking from the recorded video of the workshop (discussion and presentation), 4) The transcript of the video recording of the question and discussion part of the special seminar. They were converted into a text format and imported into NVivo to code and generate themes. Thai was translated into English for the report.

Illustrative quotes are labelled with a pattern displaying the participant ID and the source of data. Data sources include: from the open ended answers in the questionnaire (ques), the worksheet for practice using the framework (worksheet), note taking from the recorded video of the workshop (workshop), question and answer section of the special seminar (seminar). For example, (B-02, ques) means the result is from participant ID B-02, which answers a question in the questionnaire. The final themes are shown below.

Themes 1: Feedback on using the proposed framework.

Themes 2: Process to design an exhibit and its relevance with the proposed framework.

Themes 3: Factors that influence the designer in choosing a technology.

Themes 4: Opinions and discussion of VR technology.

9.4.2.1 Theme 1: Feedback on Using the Proposed Framework

This theme focused on user comments and feedback from participants using the proposed framework. It includes advantages of the framework, weak points of the framework, and recommendations to improve the framework.

1) Advantages of the framework: the framework is a good guideline for designing a VR exhibit. It helps science educators (users) who are not technology developers to design a VR exhibit (B-02, workshop). It helps people who are unfamiliar with VR technology and do not understand how to design a VR exhibit and what factors one must think of when designing the exhibit. The framework helps to think about how to design a VR exhibit (B-02, workshop).

It is a good framework to guide to start developing a VR exhibit, but some factors are mentioned to infrequently, for example, content and safety (B-02, ques). The framework is a guideline for designing an exhibit which has all the needed detail (B-05, ques). It is interesting and can be used in developing exhibitions (C-01, ques). The framework is useful for museums which helps museum staff learn the concepts of the virtual experience and motivate them to use new technology (O-05, ques).

2) Weak points of the framework: some participants have never used VR before or have limited VR knowledge, they cannot imagine every detail of the VR system, which limits their ability to use the framework to design a VR exhibit effectively (A-03, ques). For example, participants do not understand how to use the VR controller, which is difficult when designing each button’s function (group A, workshop). Participants can not draw (avatar body) because they never use VR before (A-01, workshop).

The framework has many elements in detail. It takes time to fill in the worksheet, and a participant mentioned they cannot complete all of them in time (D-02, ques). The sequence of using the framework was found to be complicated in using framework part 1 before design content which exists in part 2 (D-01, ques).

Some participants need help understanding what the framework means and how it helps them think to develop the real exhibit (A-02, workshop). They want a defined meaning of the framework, components and factors to design (B-03, ques). Some points and some words in the framework should be clearer and have an explanation (B-01, ques) (O-07, ques) so the user can more easily understand each element of the framework.

3) Recommendation for improving each component in the framework

Content design: a participant mentioned that should has scope of the content prevents adding multiple content for one exhibit (C-05, ques). Participants want to select more than one Interaction style (O-03, ques), but the online worksheet does not allow this. It found that many groups choose more than one Interaction style for designing the content (group B, worksheet), (group A, worksheet), (group C, worksheet), but the aim of the framework intends for the designer to choose one as the main style of interaction. Another issue is the Narrative story. The result found that some groups only set the scene with an introduction to the story (group B, worksheet) (group G1, worksheet) (group G2, worksheet), some groups only define steps of the situation or provide an activity for players (group D, worksheet) (group C, worksheet). The Narrative story should add more instructional detail.

Action design: the result found that many groups designed multiple actions (activities in which people interact with the system). A participant mentioned the Action design supports only one action in the game but should support more than one (O-04, ques). A group of participants wanted to provide more than one input controller and a free hand to interact with the system, suggesting that “children might not understand how to use the controller, so freehand might be the easy way for children to interact with the system.” (group G2, workshop). Some participants did not understand how to control the avatar in the VR system, so it caused them to define the Action design. The design of the framework should be simple and easy to understand (C-05, ques).

Social interaction: A participant mentioned that we should put an example appearance of an avatar along with the Avatar representation. It will make the participant more understanding because the avatar might be new for people who are unfamiliar with VR (O-03, ques). Some groups wanted to design more than one avatar character, but the framework provides only one layout (group B, worksheet). Figure 9.6 shows an example of avatar design from a group of participants.

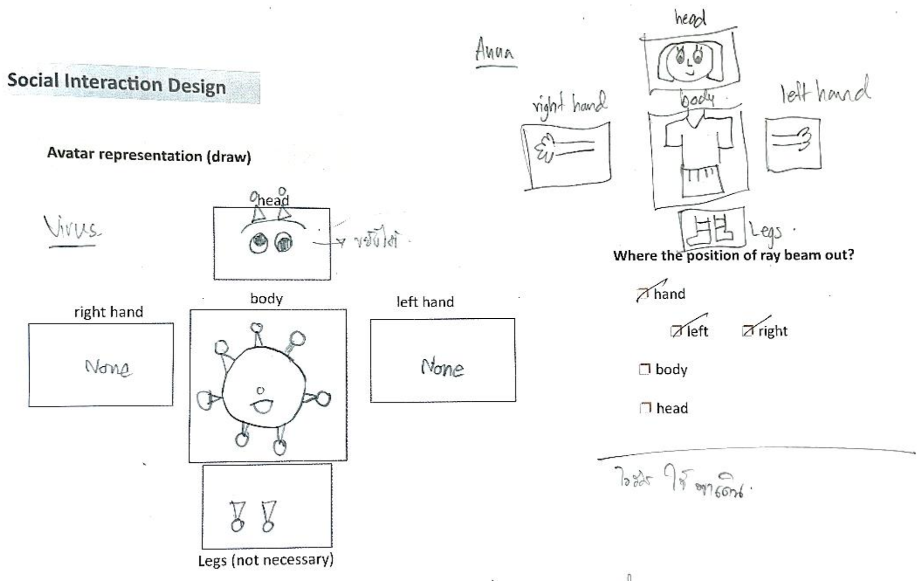


Figure 9.6 Example of avatar drawing in the worksheet, participants draw more than one avatar.

System Design: the result found that some groups specify the information on the System structure incorrectly (group C, worksheet). Some groups drew an exhibit environment to describe how to install the exhibit (group D, worksheet); see Figure 9.7. Many groups drew a picture or used a picture to describe their design of the exhibit (group B, worksheet) (group G3, worksheet). Two groups specified information on how to open the exhibit and how to close the exhibit with easy words “when the museum opened and when the museum closed” (group G3, worksheet) (group G2, worksheet) but did not explain in detail. Indeed, the participants misunderstanding between the physical exhibit and system software of the exhibit. It intends participant define how to manage system software of the VR exhibit daily, the exhibit need to open and close in every day. Another issue found in the how to reset the system element, three groups of participants specified information based on hardware but did not think about software issues and visitor experience or preparing for the next visitor to play (group A, worksheet) (group B, worksheet) (group C, worksheet).

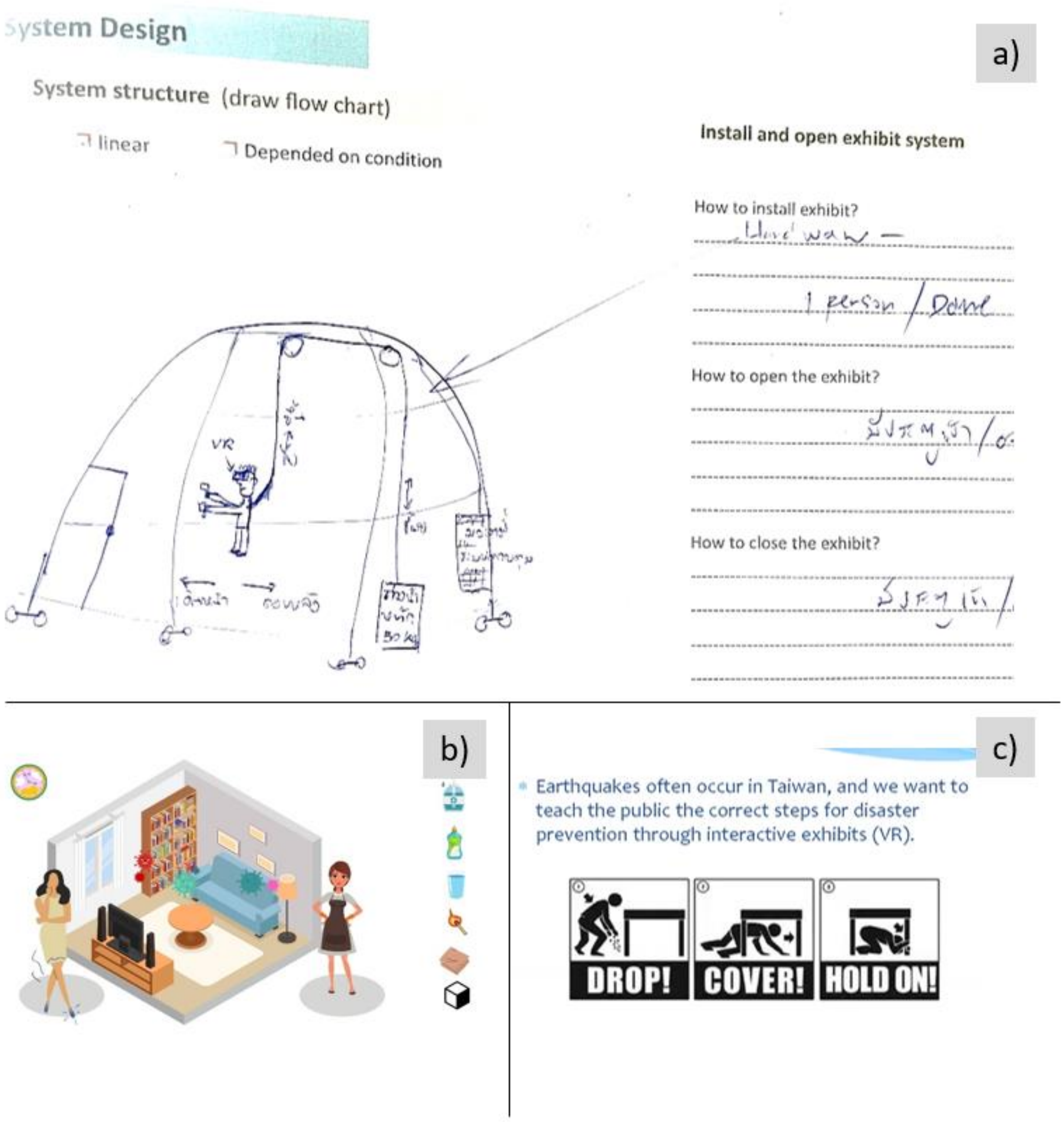


Figure 9.7 Example of pictures that participant used to show their new exhibit. a) An example image participants drew demonstrating exhibit structure for installation. b) An example image participants created illustrating the environment of the exhibit. c) An example of a picture that participant used to communicate their exhibit.

Safety and health: the result found some participants did not consider providing a charger cable for charging the HMD, which mentioned “charge devices every day” (group G1, worksheet) and “charge device before use” (group G3, worksheet). They might believe the HMD is able to be used all day, or they might not think about continued use of the HMD. A short lifetime of the VR headset might result in the HMD being unavailable for visitors to use. A suggestion for managing the area is to make the boundary obvious so other visitors can see the player playing the exhibit (D-01, ques).

9.4.2.2 Theme 2: Process to Design an Exhibit and Its Relevance with the Proposed Framework

The main source of information was obtained from participants' feedback on open-ended questions on the questionnaire describing the process of and their role in developing an exhibit and explaining their responsibilities. The results can be summarized in the steps to develop an exhibit as follows.

Step 1 Research content: to develop a new exhibit, start with the topic that initially aims to deliver knowledge to visitors, but it is unclear what the topic is. It is in the form of a rough scope idea of the topic. In this step, science educators will research data around the topic to understand the context of the exhibit's topic (O-03, ques) (B-01, ques) (B-02, ques) (B-05, ques). An exhibit is introduced along with developing an exhibition (C-01, ques) (C-02, ques) (D-04, ques). Collecting data can be done in many ways: online data (B-04, ques), from experts (B-04, ques), published papers of previous studies (O-02, ques), and brainstorming (A-01, ques) (C-03, ques) (D-02, ques). To consider this step will happen before use the proposed framework to guide design the new exhibit.

Step 2 Summary to define topic and content: this step summarises the information from step 1 and concludes with the idea to design the exhibit (A-01, ques) (A-04, ques). It should confirm the topic and content of the exhibit (O-01, ques), define the objective of the exhibit (A-03, ques) (B-02, ques), define the input, output and outcome of the exhibit (B-03, ques), and confirm the theme, venue, target audience, budget, etc. (O-04). The proposed framework supports the design of an exhibit in this step. Input and Output elements of the proposed framework Part 1 provide the designer to define the input and output of the new exhibit. The Content Design component offers an element for the designer to specify Learning Outcome.

Step 3 Detail Design: this step involves content planning (O-04, ques), defining the storyline (A-03, ques) (O-05, ques), and designing how to present the story (B-01, ques). Consider the display technique and method (O-01, ques), and select media and technology to present the exhibit (B-01, ques). Finally, summarise the design model for developing the exhibit (O-01, ques) (C-02, ques). In this step, if the exhibit uses an outsourced company to develop the exhibit, this step will initiate the discussion with the outsourcing company. Almost the task of this step involves the Content Design of the proposed framework. Define the display technique and method of this step involved with Action Design and Social

Interaction of the Proposed Framework. TTF Check of Part 1 of the proposed framework will confirm the selecting technique.

Step 4 Develop exhibit: after having detailed the exhibit's design concept, it will be brought to the developer to create the real exhibit (A-01, ques) (A-03, ques) (B-01, ques) (B-02, ques) (B-03, ques) (B-04, ques) (C-01, ques) (C-02, ques) (C-04, ques) (D-02, ques) (O-01, ques). It focuses on techniques to make the exhibit, including drawing the exhibited model (A-02, ques), building a 3D model of the exhibit (C-04, ques), researching information on materials/equipment for developing the exhibit (C-02, ques), select material (C-04, ques), buy material (A-02, ques), and integrating each part of the exhibit to build the prototype (A-01, ques) (B-04, ques) (C-04, ques) (A-02, ques). Consider this step less involved with the proposed framework, except only the interaction technique to make the exhibit that will confirm from the previous step by TTF Check element. This step is a development step, more technical.

Step 5 Evaluation: after building the exhibit, its performance is evaluated (B-02, ques) (B-03, ques) to find issues and areas in need of improvement (B-04, ques). The evaluation is summarised, and improvements made to the exhibit (A-01, ques). This step is an evaluation process which less involved with the proposed framework.

Step 6 Installation display: after finishing developing the exhibit, it is displayed in the exhibition hall. It includes planning how to display the exhibit (O-04, ques) (O-05, ques), setting up the exhibit (C-01, ques), displaying (B-05, ques), delivering the exhibit and training staff (C-02, ques). The Proposed Framework provide guideline to consider when setup exhibit in museum environment. The System Design component, and Safety and Health components let the designer create a plan to display the VR exhibit.

Step 7 Maintenance: Maintenance is quite important to make the exhibit ready for visitors to play in every day. Regularly maintaining the exhibit allows it to serve visitors for an extended duration (O-03, ques). This step does not involve the proposed framework.

9.4.2.3 Theme 3: Factors Influence Designer in Choosing a Technology

The use of modern technology is often desirable when choosing technology, simply because it is modern. It should be new technology suitable for the display exhibit and providing visitors easy access (B-05, ques), “Offering a wow factor and fitting in with the objective” (D-03, ques) communicates the idea of using new technology for the display, in combination with traditional approaches (C-01, ques). Choose technology that makes the exhibit outstanding (O-01, ques). However, the technology should be easy for people to interact with (A-02, ques) (D-01, ques), “We should not choose interactive technology that is difficult to use and understand, but rather choose games that children can understand.” (O-03, ques).

Choosing technology based on the advantage of each technology and considering the outcome of technology can help to achieve the goal of the exhibit (B-01, ques) (B-02, ques) (O-04, ques). It depends on the intended design characteristics of the exhibit and how to present the exhibit (A-01, ques) (C-03, ques). Technology support creates a new learning experience, and the technology is “affordable and available” (O-06, ques).

Another consideration is feasibility. “Can the technology be installed and maintained in the long term with the resources we have?” (O-07, ques). The time available to develop the exhibit (C-03, ques) must be considered along with whether or not the developer has the expertise to use the technology to develop the exhibit (D-04, ques). It depends on cost and budget (C-03, ques) (D-04, ques) (O-01, ques) (O-04, ques). Safety is one factor to consider, “The technology that we select should be safe and harmless to the human body” (O-01, ques). Choose technology based on the target age of visitors between 12 to 30 years old (O-02).

9.4.2.4 Theme 4: Opinions and Discussion of VR Technology

This theme focuses on opinions expressed about VR technology and the issue of using VR technology, which are relevant components of the framework. It should consider when designing a new exhibit.

1) The Content Design: a participant mentioned that because VR is expensive and does not support many visitors to access it, the suitability of VR with respect to the topic of the content, storyline, and visiting style of visitors should be considered. Only then should one decide to use VR (B-02, ques). To consider why choose VR technology, and what kind of the content suitable for VR. One direction that help designer think is that consider its advantage. The following are the benefit of VR that participants discussed.

VR can simulate scientific theory which is difficult to demonstrate in the real world. For example, simulate the movement of the ball according to the projectile formula (group A, workshop), chemistry visualization using large chemical models, allowing people to walk around them and understand much more about their structure (seminar).

Safety is one of the benefits of using VR over other technology (seminar) (A-02, workshop). For example, the objects that you might not be able to approach closely, such as steam engines, “You couldn’t safely go in and put your face very close to a working steam engine, but in VR, you can go close to it. You’re not going to be in any danger from the moving part. You can do things like put too much coal in the engine, causing it to overheat in VR, but you couldn’t do that safely with a real engine. Therefore, for situations where safety is a concern, but you want people to learn about the topic, VR is really good” (seminar).

VR enables museums to display delicate artefacts, allowing visitors to interact with the artefacts, which cannot be done in real museum settings (seminar). Using VR decreases the area demand to display the exhibit (group A, workshop). VR enables the museum to re-display an exhibit that has been moved elsewhere. It reduces the cost of the hardware to display (C-02, workshop), helps to restore the original appearance of history, and it is better to display the exhibits through the combination of technology and art (O-03, ques).

VR “allows people to travel to places that don’t exist” (O-03, ques), and “users can experience a new world or area without having to actually be there” (O-07, ques). VR provides a real learning experience. It led to inspiration and long-term interest (B-02, ques). People are able to access VR everywhere and at any time (D-04, ques), they can play even when in a limited space (B-01, ques), and it allows players to play at home (D-02).

2) The Safety and Heath: motion sickness is one issue of concern when using VR. A participant asked about motion sickness and VR (O-02, workshop) and what factors should be of concern when designing a VR exhibit to reduce visitors’ motion sickness. Ethics is another issue of concern. For example, should young children be allowed access to VR? Manufacturer recommendations warn not to permit children below 13 years old to use VR HMD, though this decision should consider not only hardware issues but also content design issues. VR technology is much more immersive and real. It is exciting and attracts players who desire to play. Ratings of applications available for players to play currently do not prevent children from accessing unsuitable content. The suitability of content concerns how they judge what is real and what is fake and whether children are aware that it is a synthetic experience (seminar). Another concern is data protection and privacy, in which the performance of HMD is able to capture 3D representations of the whole body of people without asking for consent (seminar).

3) The Social Interaction Design: this research aims to improve social interaction between people when play the VR exhibit, by provide Social Interaction Design features. However, a participant raised a concerning issue of using VR. It is possible to increase the social distance between people (D-01, ques) since each player wears HMD during the experience with VR. Another question that arose is whether or not Metaverse immersive technology isolates people from the real world? (seminar). In the virtual world, players have individual and social space, believing that the design will provide people with social experience together and allow them to experience things together rather than isolated. Therefore, the design of the experience and the exhibit should embed social features, which is a positive feature of immersive technology (seminar). This is emphasized that the Social Interaction Design is crucial for eyewear technology.

9.5 Discussion

This section will discuss what finding in evaluating the framework and how to adjust the proposed framework. There are two things to adjust the proposed framework: adjusting the step of using the framework and adjusting each component. Understanding the step to create a new exhibit led to improving steps on using the framework. It will be discussed as follows:

9.5.1 Exhibit Design Process and Step of Using the Proposed Framework

Frist, it summarises the process of designing an exhibit which analyses information in section 9.4.2.2 Process to design an exhibit and information that participants respond to questions about developing a new exhibit. To understand the actual process that museums use to design a new exhibit. The process of developing a new exhibit was summarized into seven steps: research content, define the topic and content, design detail, develop the exhibit, evaluate, install, and maintain. Figure 9.8 summarizes the steps of creating a new exhibit.

9.5.1.1 Step to Create a New Exhibit

At each step, people who get involved in developing the exhibit are different. At the beginning of the development process, the topic and content are quite important, and science educators, curators, and researchers will be the key people to research the content. After the content is collected, the next step is to change the content into an experience. The exhibit designers will be the key people to generate ideas to design the exhibit. After the storyline of the exhibit is generated, next is selecting technology to present the content. To design how to display the content and what technology is that suit for the exhibit, the developers and technicians will start to get involved in the development process. They have more technical knowledge about the technologies and how to implement them than science educators and designers. Therefore, they can help to decide to choose the technology to display the exhibit.

After the detailed design of the exhibit has been defined, including the technology to display, the next step will be to send the design detail to development. In the development processes, developers and technicians are the key personnel, as exhibit and software developers have more in-depth, detailed knowledge about the development process than science educators. In the development process, the exhibit designer will create a 3D structure model of the exhibit that can be used to construct the structure of the exhibit. This step involves many tasks in building the structure and creating display content. The developers will use their skills to select techniques to implement the exhibit. The expertise of the developer is a factor to consider when choosing the technology (D-04 mentioned). At the end of the development process, each part of the software and hardware will be integrated for testing. In developing a VR exhibit, the software is more important than the hardware (physical objects). However, the VR exhibit needs to design the physical environment for display in the exhibition hall.

The prototype of a new exhibit will then be evaluated for quality. The evaluation will test the accuracy of the exhibit in terms of scientific content and mechanics. All people will take part in this step. If an issue is raised, the exhibit will be improved. Once all the issues are solved, the exhibit will be set up in the exhibition hall. The developer's team will hand over the exhibit to museum staff. The museum staff will manage the exhibit, and the technician team will support maintaining and repairing the exhibit to serve visitors daily.

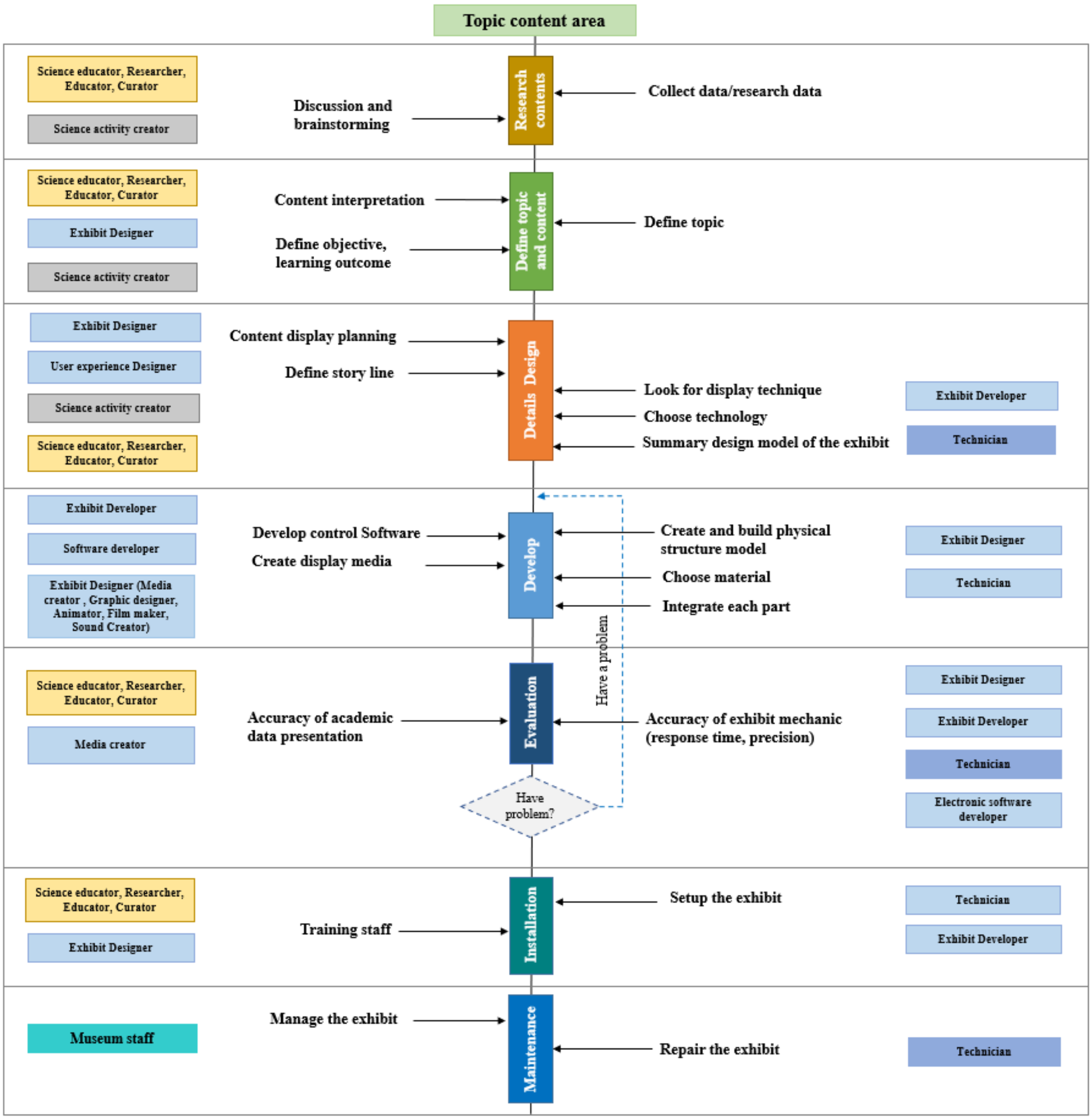


Figure 9.8 Summary of the process to develop a new exhibit and the people who get involved in each step.

9.5.1.2 The Steps of Using Proposed Frameworks

The initial design, the step to using the proposed frameworks, was divided into two steps. First, check requirements and TTF to investigate whether VR is suitable for developing the new exhibit. Second, the design details of the VR exhibit. Figure 9.9 show the step of using the framework. After evaluating the proposed framework, it found that the actual step to create the proposed framework involves with design the content first and then choosing a technology to display. The results from the analysis of the steps of creating a new exhibit are shown in Figure 9.8, and results of the practical work in the workshop, everyone defines the Content Design component first and then returns to Part 1. Participants stated that this is the same as the process of designing a new exhibit. The topic of content and planning the content and story are defined before selecting a technology to display the exhibit. Therefore, the results suggest adjusting the framework by defining the Content Design first and then continuing to Part 1 and the rest of Part 2, including Action Design, Social Interaction Design, System Design, and Safety and Health.

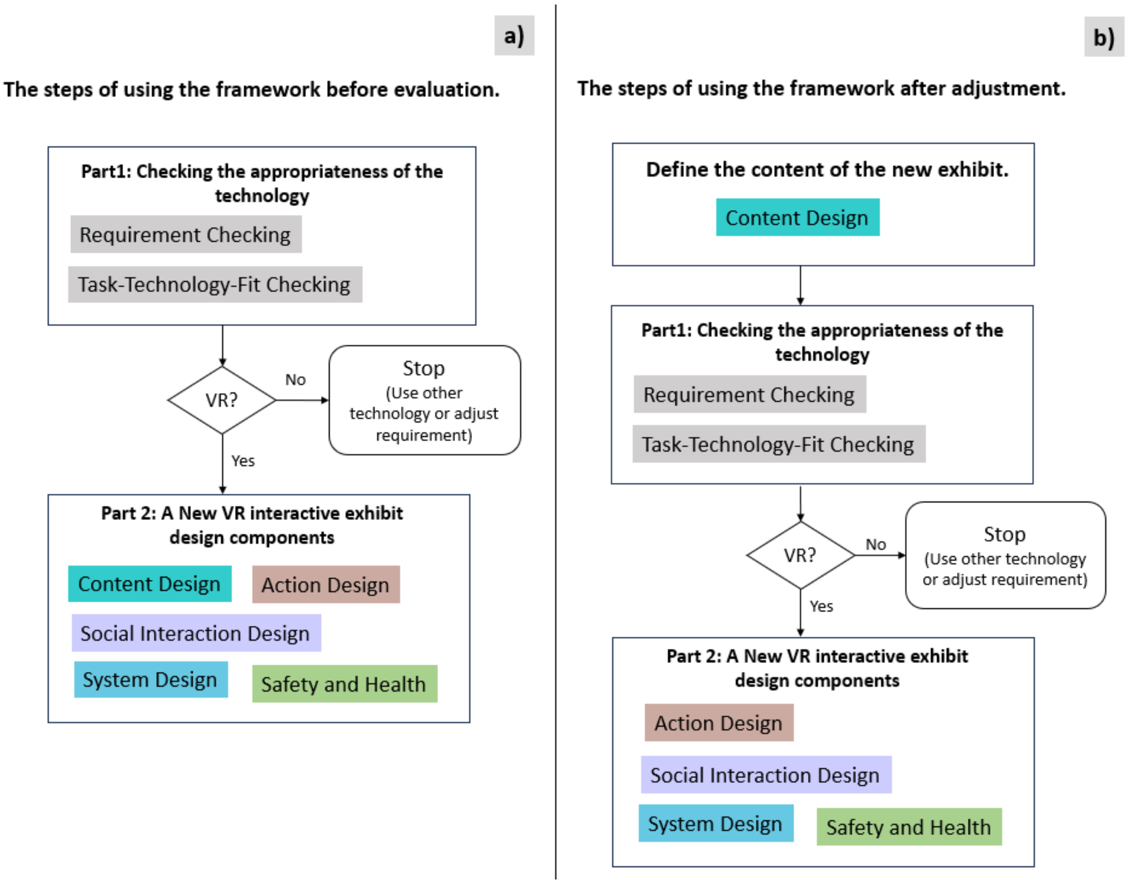


Figure 9.9 The steps of using the proposed framework compare before and after evaluating the proposed framework.

9.5.2 Improving Each Component of the Proposed Framework

The result shows that most participants agree the framework helps guide the design of a new exhibit, with positive feedback. It especially helps people who are unfamiliar with VR technology able to design a VR exhibit. According to one participant stated, “It is a solid framework” (O-07, ques) because it provided in-depth detail of the VR elements and features one should consider in the design of an interactive display in a museum setting. Consider the summary process to develop an exhibit above Figure 9.8. The framework is able to help designers in the detailed design process. It can help as a guideline to design the detail of the VR exhibit and help to plan, install and manage the exhibit for visitors to experience. It helps to decide whether or not to choose the VR technology to develop the exhibit. The framework helps the designer carefully think about the necessary details to develop a VR exhibit in advance before sending the design to develop. Especially important, it helps designers who might be unfamiliar with VR technology to design a VR exhibit.

However, the result found some participant could not imagine the depth detail of every component due to some feature of VR is quite new such as 3D avatar to represent a player in VE, the movement in VE using HMD and controller, and interaction in VE. Particularly, participant who never use VR before. In spite of, the framework provided them for the essential features for design the VR exhibit, it needs to put more examples that will help them to imagine. The suggestion from the results to adjustment components of the framework as follow.

9.5.2.1 Improvement of the Elements of the Content Design

The content design should improve two things as follows:

1) Narrative story: as the results found, participants did not specify both things, the telling story and the sequence of what happened in the story, which intended the participants to define both. So, this will improve by applying a storyboard style [87] , allowing the designer to draw and specify the message of each scene. And provide more information on how to tell a science story. Figure 9.10 show an example of storyboard of the Camouflage VR exhibit.

2) Overview of the new exhibit: the results found that every group expressed their thought about designing a new exhibit by drawing a picture or using an image. So, the framework worksheet will provide an area for illustration ideas to create a new exhibit.

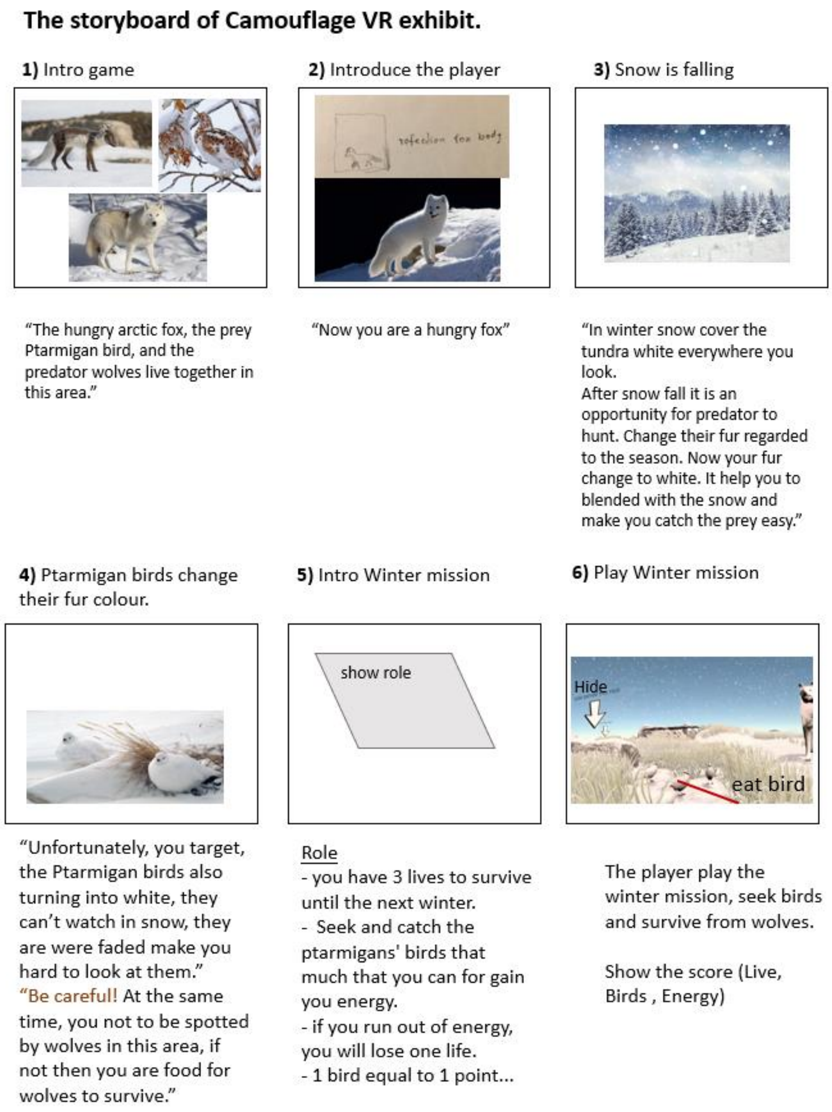


Figure 9.10 An example of storyboard to narrative the story of the Camouflage VR exhibit.

9.5.2.2 Improvement of the elements of the Action Design

The Action Design component did not find specific issues, except some participants could not imagine the action in the VE. So, it will improve by providing more examples of interaction in the VE. Show more examples of the action and effect that enable to create in the VE. Figure 9.11 show examples of simple interactions that can create when using VR technology. The following information will be added to the framework worksheet. Figure 9.12 show an example scene of visual feedback that can create in VE. It shows the snow falling effect and shows visual feedback after a player selects a bird. Figure 9.13 show an example scene of visual effects that can create in VE. It shows the movement of the steam engine, the spread of steam, and the fire in the furnace.

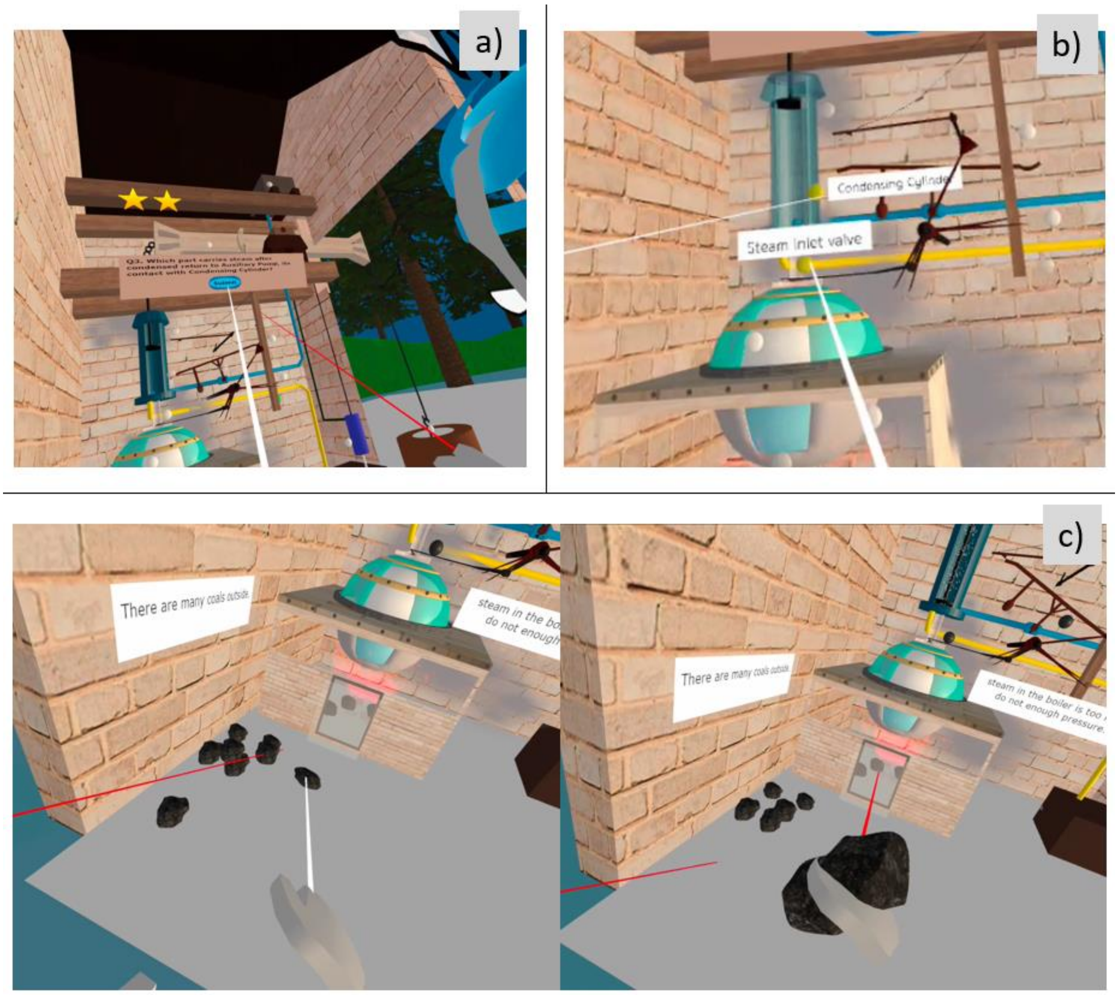


Figure 9.11 Examples of interaction. a) Point and select an object. b) over an object and display label. C) point to select an object and then hold it on hand, enabling it to move that object.

Figure 9.12 An example scene of visual feedback that can create in VE, snow a falling effect, transforming a bird into a number.

Figure 9.13 Example scene of visual effect and objects movement that can create in VE; movement of the steam engine, produce smoke, produce steam, create fire.

9.5.2.3 Improvement of the Elements of the Social Interaction Design

The results show participants need more examples of the Avatar to help their understanding and imagine the design of the Avatar's characteristics. Locomotion in VE is quite new for people who are unfamiliar with VR technology. It is a bit difficult for people to understand how Avatar is controlled by players in VE, especially people who never try VR HMD before. So, examples of the Avatar and an explanation of how device and player movement map to the Avatar will be provided. The following information will be added to the framework's worksheet. Figure 9.14 shows examples of mapping diagrams between a player and an avatar. Figure 9.15 shows an example of an Avatar representing each player and an example of their social interaction in VE.

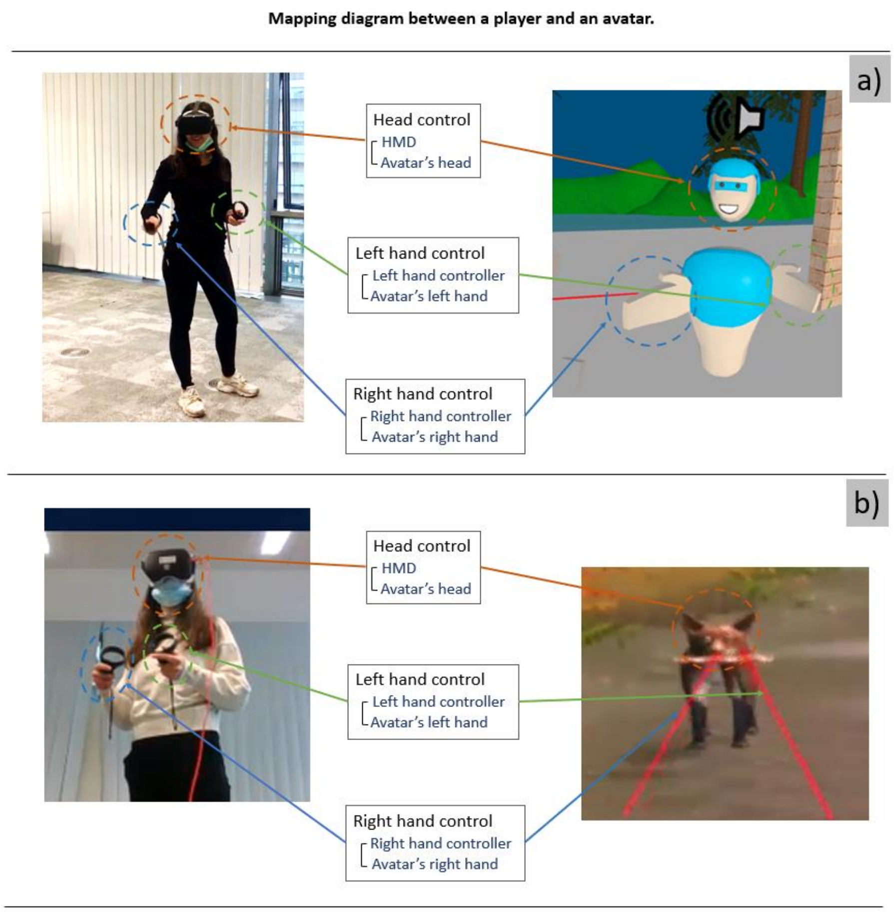


Figure 9.14 Example of avatar presentation player in VE and show mapping diagram between a player and an avatar. a) show an avatar in the case that has the head, left hand and right hand to represent the player. b) show an avatar in the case without visually representing hands.

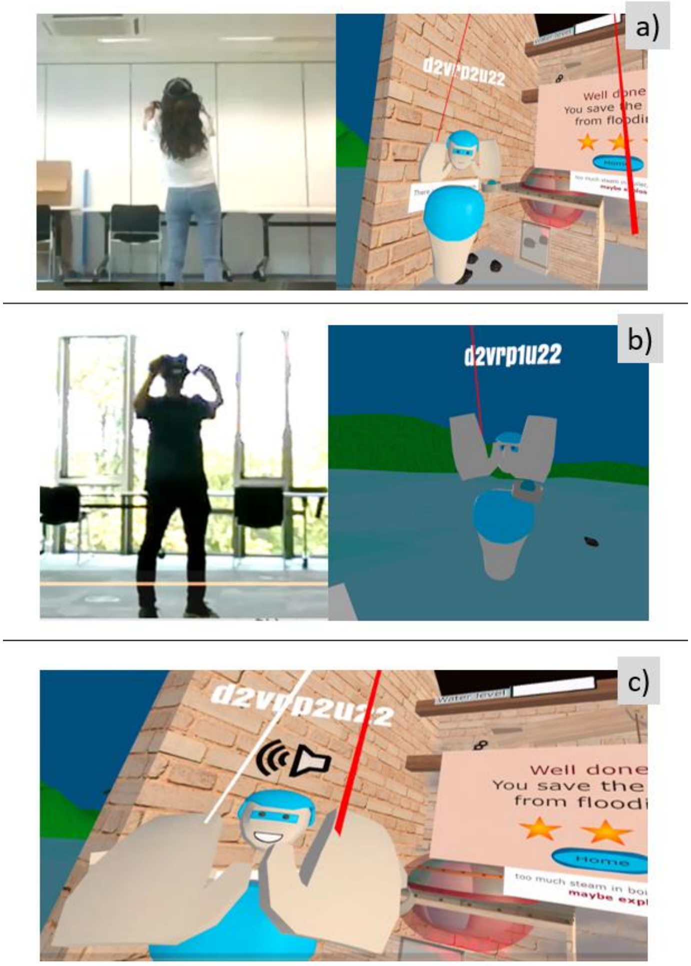


Figure 9.15 An example of avatar movement synchronising with player movement and an example of social interaction in VE. a) Player 1 and avatar represent Player 1 in VE. b) Player 2 and avatar represent Player 2 in VE. c) social interaction between Player 1 and Player 2 and their avatar in VE.

9.5.2.4 Improvement of the Elements of the Safety and Health

The result found that almost all participants draw an overview of the exhibit, showing the layout of the exhibit to guide discussion in groups and convey their ideas. Also, the result found that some groups expressed their thoughts about installing the exhibit by drawing the exhibit structure. Therefore, the framework should provide an element for drawing the exhibit structure and environment, where area to put HMD, where area for players to play the VR exhibit, in the System Design Component.

9.5.3 Make a Decision to Choose a Technology

Indeed, the use of new technology is one of the first things people think of when designing an exhibit. Many participants mention choosing a technology, for example, “wow technology” (D-03, ques). This means that the desired technology is already defined, so the designer should design the content and experience suited for delivering with that desired technology. On the other hand, if the design does not require specific technology, technology will be chosen according to the content and experience design. However, the precision of the technology should be tested, as it was found that this factor can affect user experience in a negative way (results of Chapter 5).

Choosing technology is also based on the skill of developers in using the technology if the exhibit is developed in-house (not hiring an outsourced company). Therefore, the expertise of those who will implement the technology should be considered (D-04 mentioned). If the developer is unskilled, it will make it difficult to develop the exhibit successfully. Other factors mentioned by participants in choosing technology are the availability to use, the time limit to finish the project, and the cost and budget. Some technologies take more time to implement.

9.6 Conclusion

This study intends to evaluate the helpfulness of the proposed framework by conducting a workshop with invited participants. The study aims to answer three questions. Does the proposed framework have the capability to help the designer design a new VR exhibit? Are the framework’s components appropriate? How does the proposed framework help the designer create a new VR display? The study’s activities include attending the special seminar to gain knowledge about VR immersive technology; attending the workshop, which happens onsite and online; participating in practice using the framework in the workshop; and then participants giving feedback at the end of the workshop on the questionnaire. In the study, 23 participants joined the workshop. The study uses both quantitative and qualitative data. The quantitative helpfulness measurement uses a self-report questionnaire with a five-rating scale (2, strongly agree, to −2, strongly disagree). The qualitative data was gathered from open-ended questionnaires, workshops observation, worksheets of the framework used, and discussion in a special seminar.

The results demonstrate that the proposed framework helped design a new VR exhibit, with 77.31% positive feedback. The safety and health component received the lowest score of helpfulness (65.21%). The participants also gave positive feedback on the appropriateness of each framework component, part 1 overall 78.26 % and part 2 overall 78.26 %. The information is sufficient to support a designer's use of the framework to design a VR exhibit, receiving positive feedback of 78.26%.

The participants states that the framework for designing a new VR exhibit is clear in detail. It found that the framework helps the designer with the design details of the exhibit and helps guide the design of a VR exhibit's essential elements. It assists with the choice of technology to ensure that VR is suitable for developing the exhibit and to plan, install and manage exhibits for visitors to experience. The framework also aids people unfamiliar with VR to design a new VR exhibit. However, some participants need help imagining the depth of detail of every feature of VR, so it needs to provide more examples for the designer.

The results from this study suggested improving the proposed framework, which can be divided into two parts: improving the steps of using the framework and improving the components of the framework. The investigative process of designing a new exhibit resulted in changing the steps for using the framework. The adjustment begins with defining content design, followed by examining the appropriate VR technology and its requirements (proposed framework part one), and if the answer to checking TTF is 'yes', then continue to define part two (action design, social interaction design, system design, and safety and health). Second, improve each framework component. Content design can improve the narrative story element by providing a storyboard for designers to define each scene of the story's sequence and message. An example of a way to tell a science story should be included, and it should provide a space for expressing thoughts on a new exhibit via drawing a picture. Action design offers more examples of interaction with VE and examples of visual effects and visual feedback that could be generated in VE. Social interaction design supplies more illustrations of avatars and explains how the player controls the avatar, showing instances of social interactions in VE. Safety and Health component should provide space in the framework worksheet to illustrate the exhibit structure's layout. It is used to plan the VR exhibit's structure and environment.

Chapter 10 Conclusions

10.1 Thesis summary

This thesis made the following statement in its Introduction:

This research focuses on improving how VR is deployed in STEM museums by proposing a framework for facilitating conversations between developers and exhibition designers to create a VR exhibit. It is the bridge in collaboration design between technologists and non-technologists to design a new VR exhibit. The proposed framework incorporates content design, interaction design, social interaction design, system design, health and safety. *Content design* comprises the factors for designing a learning experience, changing techno-scientific content into an experience. *Action design* is the suggestion feature for designing how visitors interact with a VR exhibit. *Social interaction* provides guidelines to support designing social interaction between visitors for the VR exhibit. *System design* comprises the essential features for designing a system for each VR exhibit in a STEM museum. Finally, *health and safety* are the suggested factors that make visitors safe when using a VR exhibit.

The studies were conducted to answer the main research question of how we can create a new interactive exhibit with consideration for using VR immersive technology while supporting social interaction between visitors. This larger question may be broken down into five sub questions, as follows.

RQ1: how does the choice of technology used to create an exhibit affect visitors' experience?

RQ2: what are the factors that should be considered when choosing technology?

RQ3: what kind of activity will create social interaction in VR?

RQ4: what kind of social mechanics and design features of VR is best suited to deliver a science experience via VR?

RQ5: how does 3D versus 2D view impact user experience in term of learning and memory in a virtual environment?

Chapter 2 presented a literature review which provided knowledge background for this research context, related work and issues surrounding VR and learning in museums. Chapter 3 provide an overview of the proposed framework and the process of constructing the proposed framework. Chapter 4 provided an understanding of interactive exhibit characteristics, immersive technology and VR in the museum context by conducting a museum-based observational study to find issues and improvement gaps. Chapter 5 described an empirical study, conducted to understand the factors that affect users' experience when using different types of interfaces, and factors that influence exhibit designers' choice of technology. The information from this study provided for the proposed frameworks part 1. Chapter 6 detailed an empirical study, conducted to investigate a method to support social interaction for VR exhibits, providing information for the proposed framework's social interaction design. Chapter 7 comprised a study of how to design content for a VR exhibit which investigated how the users' perception of the virtual environment (2D versus 3D) affect learning and memory. It provided information for the content design of the proposed framework. Chapter 8 validates the proposed framework in the natural museum setting. To evaluate the components of the proposed framework through the VR exhibits and whether they are appropriate and usable. The two VR exhibits from previous study were adjusted feature match with components of the proposed framework and deployed in the museums, allowing visitors to play to gather feedback and investigate issues supporting the proposed framework. Chapter 9 evaluated the proposed framework by conducting a workshop on using the framework and gathering feedback from the participants. The purpose of this chapter was to assess the framework's usefulness in helping the designer design a new VR interactive exhibit.

10.2 Research Questions

The overall research question is about how we can create a new interactive exhibit with consideration for using VR immersive technology while supporting social interaction between visitors which it be broken down into five sub questions:

10.2.1 Research Question RQ1

RQ1: how does the choice of technology used to create an exhibit affect visitors' experience?

This question was explored in the study on an alternative design for an exhibit (Chapter 5). The study compared the user experience of three types of interfaces: gesture, tangible, and VR, which examines user experience on seven factors: attractiveness, perspicuity, efficiency, dependability, stimulation, novelty and holding power. It found features of technology choice that affect user experience in five dimensions. The five dimensions include:

- Attractiveness, which indicates overall how users were impressed with the exhibit.
- Perspicuity, which refers to how easy it is for users to get familiar with the exhibit.
- Efficiency, which indicates if the user can do a task effectively without putting in much unnecessary effort.
- Dependability, which refers to how users feel the exhibit is in their control.
- Stimulation, which indicates how exciting and motivating the exhibit is for the user to use.

However, the study did not find user experience differences in novelty and holding power. And it did not find a difference between VR and tangible-based interfaces. The result indicates that the quality of the exhibit affects user experience rather than the different features of technology.

10.2.2 Research Question RQ2

RQ2: what are the factors that should be considered when choosing technology?

The empirical results from study one (Chapter 5), both quantitative and qualitative, were analysed to answer this question. The analysis found six aspects to consider when choosing technology: novelty, ease of use, precision of the input device, task and device design, multi-modality of feedback, and quality of text in VR. In addition, the results from study five, the proposed framework evaluation (Chapter 9), found that novelty is one factor in choosing the technology that the designer mentioned; however, it should be simple to use. Another factor for in-house production is the expertise of developers to implement that technology. If the developer's team is not skilful, developing and exhibiting success is challenging. Finally, cost, budget, and time are important factors when choosing technology.

10.2.3 Research Question RQ3

RQ3: what kind of activity will create social interaction in VR?

Study two, on social interaction design in VR for learning in museums (Chapter 6), was conducted to answer this question. The experiment involved four types of interaction styles with content: explore, quiz (challenge to find a correct answer), explanation (demonstrate a principle), and complete a mission. It found that the quiz and completing a mission style produce the most conversations between players, followed by exploration. Explanation of how the steam engine works resulted in less conversation between players. However, the topic of conversation is different across the four activities. In addition, it found that players did virtual celebrations (dance, hi five) when they could answer a question correctly or achieve the mission. Players engaged in discussion to find the correct answer, and pointed out objects to explain to their partner and warn them of dangers within the virtual environment. Finally, participants used virtual greetings and hugs to encourage and call partners.

10.2.4 Research Question RQ4

RQ4: what kind of social mechanics and design features of VR complement STEM activities?

In study two, the social interaction design study (Chapter 6), the methods to connect players to provide social interaction were investigated to answer this question. One method is symmetric design, where all players use VR HMDs to experience the exhibit. Another method is an asymmetric design where one player uses a VR HMD, and another uses a PC to experience the exhibit. The result found the symmetric design offers more sense of presence, co-presence, social presence and engagement than the asymmetric design. Multi-player design is better than single-player design, as it enables players to exchange knowledge. While, the asymmetric design, using a PC connection with VR is not the best method, it provides an alternative way to connect players who stand around the VR exhibit able to communicate with people who are wearing the VR HMD to play the exhibit. This finding is supported by study four, the in-the-wild study to evaluate the proposed framework. This study found that providing a PC connected to a VR system benefits visitors and museum staff. For example, a group of visitors can communicate with a staff member who is wearing a VR HMD, and other visitors can know what happens in the VR. The staff member is able to help players if they encounter difficulties in VR. Another point is that an avatar to represent the player in the VE is essential for a VR exhibit. It enables players to perceive another player, enabling them to communicate. The pointer is one feature that was found useful to indicate things within the VE in conversation.

10.2.5 Research Question RQ5

RQ5: how does 3D versus 2D view impact user experience in term of learning and memory in a virtual environment?

This question is answered by conducting study three, content design of an exhibit in the virtual environment. This study examined the effects of design content on the 2D display in VE compared with the full 3D display, with a focus on learning, memory, immersion, and emotion. The result found that 2D view and 3D view have equal efficiency in supporting visitors to learn content and remember the story. Even though the 3D view offers higher immersion and emotion than the 2D view, it was found that increasing immersion does not affect learning and memory. In contrast, 3D views provide more immersion and tend to provoke more emotion. Furthermore, the results suggest that design experience (the story narrative, activities, and game mechanic) are a more important influence on learning and memory than increased immersion.

10.3 Contributions

This section outlines the contributions made in this thesis. This research uses various research methods to examine factors to construct the proposed framework. The main aim is to improve using VR technology as an exhibit in a museum setting. Investigate design methods to create a new interactive exhibit for the STEM museum. The main contributions of this thesis to design interactive exhibits for STEM museums summarise are as follows:

1) Established a framework that is a communication tool for collaboration between developers and designers to aid in the design of a new VR exhibit. This thesis proposed a framework as a guideline for designers to design a new VR exhibit that supports social interaction in STEM museums. This research used a mixed method approach to construct the framework: theoretical review, museum observational study, and experimental study. The evaluation results show the framework is useful for helping designers consider the essential features of the VR exhibit. The framework provides detailed information and concrete feature suggestions for designing a new exhibit and provides concern issues found in this research to help them to reduce failure. It especially helps designers who are unfamiliar with VR technology to be able to design a VR exhibit. The evaluation proposed framework by deploying two VR exhibits in the museum setting shows visitors have a positive experience after playing with the VR exhibits.

2) Study the characteristics of the interactive museum context, which focuses on STEM museums. This research investigates and summarises common and various interactive characteristics from the museum's observational study (Chapter 4). It found a common interaction structure in STEM museums, the form of social interaction, and the styles for telling stories and interaction (see Section 4.3.1.3). It found various techniques museums use to deliver immersive experiences and the approaches used to support social interaction between visitors (see Section 4.3.2.3). It found various patterns that museums use VR to deliver knowledge, patterns of time consumption in using the VR, and interaction issues using VR as a museum exhibit (see Section 4.3.3.3).

3) Investigate the factors that make user experience differ across alternative technology. This research examines how using different technology to create an exhibit has affected user experience. And suggest six aspects to consider when choosing between VR and other alternative technology (see Section 5.5.5). It helps to distinguish which technology is suitable for creating a new exhibit.

4) Investigate methods to support social interaction using VR as an exhibit. This research suggests a method to connect players so that they are able to communicate and have social interaction, using mixed symmetric and asymmetric connections. It introduced social interaction features and social mechanisms to facilitate visitors to discuss and exchange knowledge while playing the VR exhibit. It also introduced game style design features for learning and having social interaction in the virtual environment. It found that each game style: exploration, quiz, explanation, and complete a mission, has different features to induce social interaction and discussion. This research suggests that the virtual body is essential for communication in the virtual environment for VR exhibits. Voice and pointer are important features for creating social interaction and discussion, especially using pointing to highlight an object far away from the player in the virtual environment.

5) Investigate the effect on the user experience of design content in the virtual environment. This study examines 2D and 3D design content within a virtual environment and whether dimensionality affects learners' learning and memory. This research shows that there are not differences in knowledge gained and remembering the story from the VR exhibit unless 3D produces more immersion and emotion. This research provides suggestions for design content in the virtual environment (see Section 7.5.5).

6) Introduce a process for studying the design of an exhibit using new technology, leading to the creation of guidelines to help the designer design a new exhibit. This thesis offers guidelines for designing a new interactive exhibit using a new technology, which uses VR as a case study. The proposed framework of this research may be applied to study other new technology. The process starts with understanding the characteristics of the technology and then finding a gap when applying it in the museum context, while supporting social interaction between visitors. It involves finding the style of content that suits delivery with the technology and then using the core components of the proposed framework to think about the detailed elements of each component based on the technology: content design, action design, social interaction design, system design, safety and health.

10.4 Design Recommendations

This thesis contributed several design recommendations that could be used to design a VR exhibit.

Design Recommendations	Factor
1) Choose new technology that should suit delivering content. 2) Choose technology that is simple and precise to interact with. 3) Choosing technology should consider the development cost, time, and developers' expertise.	Choose Technology
4) Design content for VR should include narrative stories, activities to experience, and learning by doing instead of text-based information. It enhances visitors to remember the content.	Content Design

Design Recommendations	Factor
5) If the exhibit intends to provoke the player's emotion, use a 3D view that offers more immersion and more influence on the player's emotional involvement. 6) Design presentation of the content with multimodal design. Use at least two modes to present the content. It enables media to back up each other when some mode has an issue. For example, use text and voice-over. 7) Changing state within a game sequence should be clear, making players know their progress and easy to remember. 8) Design a change feature on the player avatar. It is difficult for players to perceive because the perspective of VR HMD in VE is first-person. 9) When using alert sound should be used at an appropriate point in the game and used for an appropriate length to notify players.	
10) Use the default function of the controller with designing interactions with content. It helps visitors quickly get familiar with using the controller. 11) Design simple actions such as one button and one action to help players remember how to interact with the exhibit.	Interaction Design
12) Provide social interaction for players by setting up a monitor to enable other visitors to interact and communicate with visitors wearing VR HMD. 13) Designing a multi-player for VR exhibits is better than a single player in which visitors can exchange their knowledge. 14) Facial expression is not a significant feature of virtual body (is an avatar that represents a player) if the layout of the objects in a VE leads players to stand side by side. 15) Voice and pointer features are important for communication in a VE.	Social Interaction Design
16) The VR exhibit system should have a page to attract visitor attention, a page to communicate the topic of the exhibit and explain what the exhibit is, a page to explain how to play	System Design

Design Recommendations	Factor
(or interact with) the exhibit, a link that can go back to the home page, and automatic system going back to home page.	
17) The boundary of the play area should be obvious for another visitor to see. 18) Provide a method to manage a queue of visitors waiting to access a VR exhibit.	Safety and health

10.5 Limitations and Future Research Directions

10.5.1 Limitation

There are some limitations in this research. For almost two years, this research conducted experiments during the Covid-19 pandemic. The restrictions associated with living during the crisis affected the time available, the number of participants, and access to museums. Some aspects of the study needed to adapt and change. Museum observational study was partly completed under normal circumstances and partly under pandemic circumstances. During the pandemic, the museums were closed. And after the pandemic, museums closed VR exhibits due to awareness of infection. It reduces the number of the case study. Study two, study three, study four, and study five were conducted under Covid restrictions.

Study two needed to change the experiment’s setting. Two participants could not stay in the same room, and so video conferencing was used to connect participants instead. Sometimes the connection signal was poor, which affected the quality of voice communication between players. And it was not possible to study how players share a physical space to experience the exhibit. Study three has a limited example of technique to implement a 2D interactive wall in the virtual environment, making the 2D view somewhat difficult to control characters in 3D VE. However, the result shows learning, and memory are not different between the 2D view and the 3D view. After analysing the data, it was found that emotion might have a relation to immersion, but the study was not designed to measure the relationship between these two factors. Due to the remote nature of participation, participants who joined the online workshop were unable to experience using the VR HMD. It could have caused them difficulty generating ideas to design a VR exhibit and use VR technology. The limitation of participants which cannot implement VR (using Unity software) to test the interaction technique that they want to use, so this reduces chance to discover issues.

10.5.2 Future Research Directions

VR technology is not new, but museums increasingly use it for exhibits because their performance and device are increasingly comfortable. Further study of interactive design in a museum context, which draws from this research, can go in three directions.

1) The proposed framework: this research uses VR as a case study to create a framework to assist designers in creating a new interactive exhibit. This study discovers essential factors for designing a new interactive exhibit which could be used as a template to study other technology such as AR, MR. This research process model may be used to create frameworks that help to design other technology which considers the components of the proposed framework. Study style of content, interaction, and social interaction that suit each technology to create a new interactive exhibit. Another direction is that the findings could be used to design a VR exhibit to fulfil the proposed framework. The choice to design some components of the framework is open to investigation. For example, the input of Action Design from the workshop to evaluate the proposed framework found that participants suggested using a free hand to interact with the VR exhibit might make visitors more familiar with interacting with the exhibit. It allows researchers to study and can compare with other input techniques. Another point, the Content Design should also study the length of media that suits VR learning in a museum setting, bearing in mind the management of queues and visitors' experience and its found effect on players' health when wearing the VR HMD for a long time.

2) VR exhibit display: designing a virtual exhibit in a virtual exhibition hall is a challenge. The results of the museum's observational study in section 4.3.1.3 show many types of interfaces in the museums. One direction for further study is to study the possibility of recreating each physical interactive exhibit in a virtual museum. It might be useful to recreate a deconstructed exhibition and create a virtual exhibition that enables visitors to experience the exhibit still onsite or online using VR technology.

Another direction is to create a continuous VR onsite experience, which offers many visitors to play the VR experience together simultaneously and in the same area. Figure 10.1 shows an example of continuous experience presented by the workshop participants to evaluate the framework. The exhibit allows visitors to excavate fossils in the same area. Study two does not explore providing social interaction for multiplayer playing a VR exhibit in the same area. It is open to study how to manage the area and groups of visitors play VR together and how to design the experience when visitors play the exhibit in the same area. And another point to consider is VR's capability to enable visitors to access the exhibit anywhere. It enables visitors at home can join the experience together with onsite visitors.

Figure 10.1 An exhibit invited visitors to excavate to discover fossils underneath. Participants presented in the workshop to evaluate the proposed framework.

3) VR experience design for children: As discussed in Chapter 9 has warned against using VR in children under 13 years old due to manufacturing recommendations [140] and concerns about unsuitable content design for children. However, children are a big group of museum visitors. It might be beneficial to study the factors that affect children's experience when using VR to understand how to design content suitable for children to access and decrease the factors that might harm children. And if the museums consider an inclusive design, the exhibit enables all ages to access the VR exhibit. It should include a design for older adults to access VR exhibits. However elderly has a concern about the issues using XR, for example, the functional limitations of the vision system, hearing system and balance, and older adults are unconfident in using new technology [134]. Study four in Chapter 8 found that some visitors stand unstable while wearing the VR HMD. Another direction open for study is how to design content that suits older adults and design VR exhibits for older adults.

10.6 Conclusion

This research proposed a framework that helps designers to design a new VR exhibit that supports social interaction. The components and elements of the framework are constructed based on a literature review, results and evidence from experimental studies and museum-based observational studies. The framework's components include part 1: checking the appropriateness of the technology; and part 2: content design, action design, social interaction design, system design, and safety and health.

While a range of studies address the main research question of how we can create a new interactive exhibit with consideration for using VR immersive technology while supporting social interaction between visitors, various studies have investigated the design features and components of a VR exhibit. An interactive display in a STEM museum context is unique; it offers a short time of playing, and edutainment media delivers scientific knowledge accessible to the public and supports social interaction. Many technology choices are available to the designer of a new interactive exhibit. This research investigates factors affecting user experience across different technology and suggests six aspects when choosing technology. The museum observational study found common characteristics of museums' interactive exhibits and problems using VR technology in museums. This research examined methods to support visitors' social interaction using VR exhibits and found design features and social mechanisms that suit communication and knowledge exchange. It shows that a mix of symmetric and asymmetric connections is suitable for museum deployment. It demonstrates that avatars, voice communication and pointer are essential for a VR exhibit to support social interaction.

This study also investigates content design for VR exhibits. It examines how visitors' learning and memory are affected when content is delivered in 2D versus 3D and determines that providing content in 2D or 3D does not affect a learner's ability to learn and remember the exhibit's story. The experience design is crucial for VR exhibit content, including story narrative, activities and game mechanics. This analysis notes that increased immersion does not equal increased learning and memory. However, immersion facilitates the inducement of emotion. Content design is explored to support visitor learning from a VR exhibit and design experiences that evoke feelings like afraid, excitement, surprise and fun.

The last part of this research was evaluating the framework. The first one was conducting an in the wild study, which validates components of the proposed framework through two VR exhibits deployed in the museum to gather visitors, feedback. The second one, the framework design and practice, were evaluated. Visitors agreed that the VR exhibits are satisfactory in content design, interaction design, and management. Visitors approve of VR exhibits in museums. The framework received positive feedback indicating that it is useful for designers considering the design details of a new VR exhibit.

Appendix A The revised version of the proposed framework.

Proposed Framework for design a new VR exhibit

V8 (after evaluation process.)

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Proposed Framework for design a new VR exhibit

Overview

The proposed framework has two main parts of component. The first part provides a factor for checking whether VR technology is appropriate for creating a new interactive exhibit according to the requirements. The second part provides components as a guideline for creating a new VR interactive exhibit.

Part1: Alternative immersive technology choosing

Requirement Checking
- Pattern using technology
- How visitor share environment
- Input
- Output
- Social Interaction and conversation
- Area require

Task-Technology-Fit Checking

Part 2: A New VR interactive exhibit design components

Content Design

- Learning Outcome
- Narrative Content Style
- Interaction Style
- Exhibit elements
- Content Element

Action Design

- Input
- Feedback
- Navigation (Movement)
- View (dimension)

Social interaction Design

- Learning Approach
- Communication
- Avatar representation
- Call attention

System Design

....

- System structure
- Reset system
- VR HMD device
- Install and Open Exhibit system

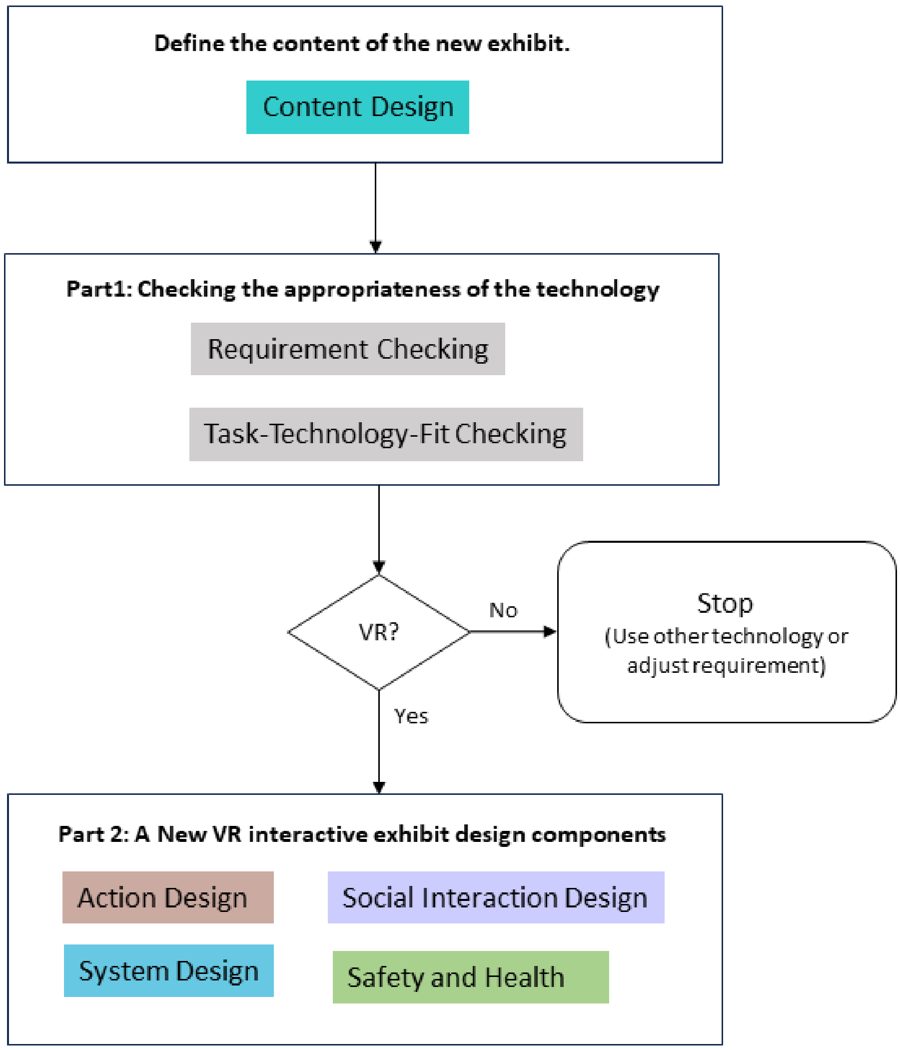
Safety and health

....

- Device management,
- Area management,
- Visitor management,
- Staff management

Step of using the framework

The step of using the framework start with defining Content Desing, followed by checking the appropriate VR technology and the requirement (the proposed framework part 1), and after the answer of checking TTF is "yes", then continue to define the rest of the proposed framework part 2 (Action Design, Social Interaction Design, System Design, Safety and Health)



STEP 1 Define topic and idea of the new exhibit

Content Design

Topic content of the exhibit : ....
....
....
....

An idea for a new exhibit (draw an overview picture to explain your idea for a new exhibit.)

Content Design (cont.)

Learning outcome

Indicates the outcome after a visitor's experience with the exhibit.

What you intend visitors do with the exhibit?

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What you intend visitors feel with the exhibit?

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What is knowledge or content that visitors get from exhibit?

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Content Design (cont.)

Learning outcome (cont.)

What is skill that visitors will develop after play exhibit?

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What value or attitude will visitor change after the play exhibit ?

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Interaction style

Define the style of activity creates the player's experience in the VE

- ❐ Exploration
- ❐ Discovery
- ❐ Simulation (simulate situation such as drive tank submarine)
- ❐ Completion
- ❐ Challenge
- ❐ Competition
- ❐ Collaboration (Fellowship)
- ❐ Create and build
- ❐ Demonstrate a principle
- ❐ Role play
- ❐ Quiz
- ❐ Fantasy
- ❐ Relaxation
- ❐ Sensation
- ❐ Sympathy
- ❐ Expression (such as can decorate avatar)

Narrative content style

❐ Passive ❐ Interactive

Content Design (cont.)

Interaction style (cont.)

Explanation of each Interaction Style

1) Exploration, an exhibit allows visitors to experience and gain knowledge by exploration, normally with unlimited time to explore. Visitors will spend their time exploring the content of the exhibit.

2) Discovery, an exhibit allows visitors to experience a storyline through the exhibit and intends visitors to discover some new knowledge or a new perspective.

3) Simulation, the exhibit simulates a situation for visitors to have an experience like they are in the situation, for example, the GPS car navigation simulator and the tractor smart farm simulation.

4) Completion, the exhibit gives a mission for the visitors with the intention of completing that mission. For example, an exhibit sets a mission for a visitor to help a patient suffering from lung disease.

5) Challenge, the exhibit challenges them to do something, gives a task for them to solve, and challenges them to test their ability. For example, the exhibit tests how fast the human body's nervous system responds to external stimuli and how fast that visitor can push a button that lights up.

6) Competition, the exhibit provides a feature allowing visitors to compete with competitors. The competitor can be another player, or game agent, or the visitor can compete with themselves to reach a goal of the exhibit.

7) Collaboration (or called **Fellowship**), the exhibit intends for visitors to play an exhibit together with another visitor. It intends for visitors to have social interaction and discussions about working and solving a problem together. It helps them exchange ideas and knowledge with visitors.

8) Create and build, the exhibit allows visitors to create or build a piece of work. Visitors will use their skills, along with the exhibit instructions, to create something.

9) Demonstrate a principle or explanation, the exhibit intends to show or describe science phenomena or a principle of science to visitors or explain how the machine work. Some exhibits allow visitors to choose or adjust some variables that affect the result of a phenomenon or theory.

10) Role play, a narrative content style where a visitor pretends to be something in the story and experiences the exhibit's story like they were that thing.

11) Quiz, question and answer style where the exhibit asks questions and visitors find the correct answer. It often found use quiz to test the knowledge visitors get from the exhibit.

12) Fantasy, this style of experience has the main purpose of inspiring visitors or making the exhibition environment more attractive. The exhibit creates a magical element, a magical experience for visitors, and bring visitors to an imagined world.

13) Relaxation, this style of interactive exhibit intends for visitors to have fun playing and makes them relaxed, more so than exhibits that deliver large amounts of information. For example, an exhibit might allow the visitors to dance on the interactive floor.

14) Sensation, an exhibit designed to involve visitors' emotions. This style is used to provoke visitors to be concerned about some issues and is intended to heighten visitors' awareness. For example, an exhibit about how difficult it is to make a decision to save human life when given two choices or an exhibit talking about climate change that shows how natural disaster kills fellow humans.

15) Sympathy, an exhibit influences visitors' emotions to care for someone who is suffering from some issue, has been affected by a bad situation, or has been affected by bad human behaviour. For instance, an exhibit on second-hand smoke shows children who do not smoke, but whose lungs have been badly affected by other people who smoke.

16) Expression, some exhibits invite players to express themselves through the exhibit. For example, the exhibit called Shadow forest allows visitors to create and play with shadows. Visitors will create an animal by hand poses or another part of the body to express their imagination. Another exhibit allows players to choose clothes to express their style.

Content Design (cont.)

Exhibit element

Narrative story (how to tell the academic content as a story, what will happen in the VE. the example or narrative story provide in the next two pages.)

Sequence of story > 1) .... 2) .... 3) ....

Define what happen >

4) .... 5) .... 6) ....

Content Design (cont.)

Exhibit element (cont.)

Narrative story (cont.)

Sequence of story >

7) ……………………………………

8) ……………………………………

9) ……………………………………

Define what happen >

10) ……………………………………

11) ……………………………………

12) ……………………………………

Content Design (cont.)

Exhibit element (cont.)

Example of narrative story of a VR exhibit.

Elements of story

Protagonist / main player = An Arctic fox.
Obstacle = Predator wolves.
Stakes = Its life.
Inciting incident = Gain energy to survive (eat birds), escape predator wolves.
Broad theme = An Arctic fox survive in Tundra environment.

The storyboard of Camouflage VR exhibit.

1) Intro game

"The hungry arctic fox, the prey Ptarmigan bird, and the predator wolves live together in this area."

2) Introduce the player

"Now you are a hungry fox"

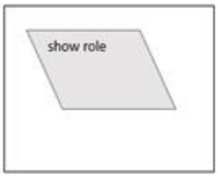
3) Snow is falling

"In winter snow cover the tundra white everywhere you look.
After snow fall it is an opportunity for predator to hunt. Change their fur regarded to the season. Now your fur change to white. It help you to blended with the snow and make you catch the prey easy."

4) Ptarmigan birds change their fur colour.

"Unfortunately, you target, the Ptarmigan birds also turning into white, they can't watch in snow, they are were faded make you hard to look at them."
"Be careful! At the same time, you not to be spotted by wolves in this area, if not then you are food for wolves to survive."

5) Intro Winter mission



Role
- you have 3 lives to survive until the next winter.
- Seek and catch the ptarmigans' birds that much that you can for gain you energy.
- if you run out of energy, you will lose one life.
- 1 bird equal to 1 point...

6) Play Winter mission

The player play the winter mission, seek birds and survive from wolves.

Show the score (Live, Birds , Energy)

Content Design (cont.)

Exhibit element (cont.)

❒ Role

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❒ Time constrains

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❒ Reward

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STEP 2 Part 1 : Alternative Immersive Technology Choosing

Features Check list

This component provides the initial features of a VR exhibit, as required by the designer's initial aim of a new VR exhibit.

Pattern using technology

Select a pattern of using VR that the museum aims to create.

- ❒ Online (virtual museum)
- ❒ Online (e-exhibit)
- ❒ Onsite continuous
- ❒ Onsite discrete
- ❒ Other thing ....

Share experience in the same environment

Define what kind of experience they want to create for visitors, allowing visitors to share experiences in the virtual environment or play alone

- ❒ Asynchronous: the VR exhibit do not provide visitors experience the VR exhibit together
- ❒ Synchronous: the VR exhibit provide visitors to experience the exhibit together.

Social interaction and conversation

Define how the exhibit allows visitors to communicate, discuss, and exchange their knowledge.

- ❒ Watch or listen only
- ❒ Less conversation
- ❒ Produce conversation between visitor

Area require (do you have area to setup ?)

Define how big a space for the setup of a VR exhibit. Can museum provide this requirement?

- ❒ No area require
- ❒ Small area
- ❒ Big area

Input

Define how the exhibit offer visitors to interact with the exhibit.

- ❒ Passive (telling story and visitor just listen)
- ❒ Interactive (visitor can interact with the exhibit)
  - ❒ Using controller
  - ❒ Using free hand *
  - ❒ Voice command *
  - ❒ Other thing ....

Output

Define output or feedback of the system.

- ❒ Visual and sound
- ❒ Additional sense
  - ❒ Vibration on controller
  - ❒ Tactile (feedback on object texture, touch sense) *
  - ❒ Smell *
  - ❒ Other thing * ....

* These options did not have supported information in this research.

TTF Check -- task and technology compatible (cont.)

The designer should test whether the intended design interaction is compatible with VR technology or not.

What is the action that you intend visitor do or interact with the exhibit?

....
....
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....
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....
....
....

How to implement, what is the technique that you will use to coding the game?

....
....
....
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....
....
....
....

Does the technique have an efficiency that visitors can interact with the exhibit precisely when using your technique?

❐ Yes ❐ No

If the answer is Yes, the VR is suitable for create a new exhibit.
If the answer is No, the VR is unsuitable for create a new exhibit.

You have to direction to select, 1) adjust the requirement or 2) use other technology.

STEP 3 Part 2 : A New VR Interactive Exhibit Design Components

Define detail the rest components of the new VR exhibit include Action Design, Social Interaction Design, System Design, Safety and Health.

Action Design

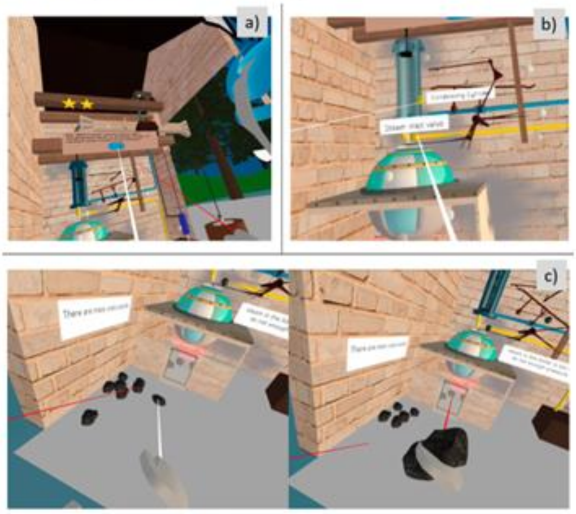
Define the design interaction of the system, what input action is, and what feedback is from the system. It refers to how visitors interact with the VR exhibit and what they get from their interaction with the VR exhibit.

Input

What is input technique visitors use to interact with the VR exhibit ?

- ❒ Controller action
  - ❒ laser point and click to select object
  - ❒ laser point drag and drop
  - ❒ other...
- ❒ Body action
  - ❒ move hand ❒ move head
- ❒ Gaze interact

Examples of interaction. a) Point and select an object. b) over an object and display label. C) point to select an object and then hold it on hand, enabling it to move that object.



Navigation

How players move and navigate in the virtual environment?

- ❒ Self walking, visitor walk around exhibit
- ❒ Using controller, visitor stand at one point
  - ❒ use both hand controller
  - ❒ use left hand controller
  - ❒ use right hand controller

An example of using controller control movement in virtual environment.

13

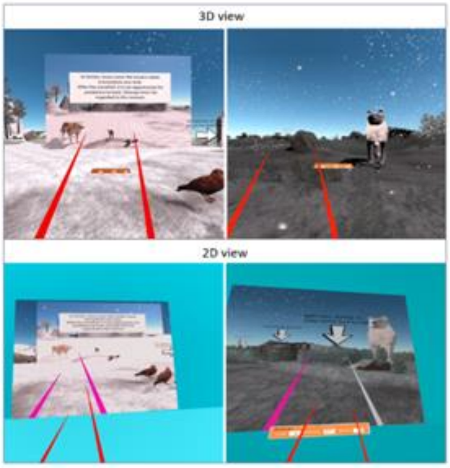
Action Design (cont.)

View

The design view allowing visitors to interact with the exhibit content

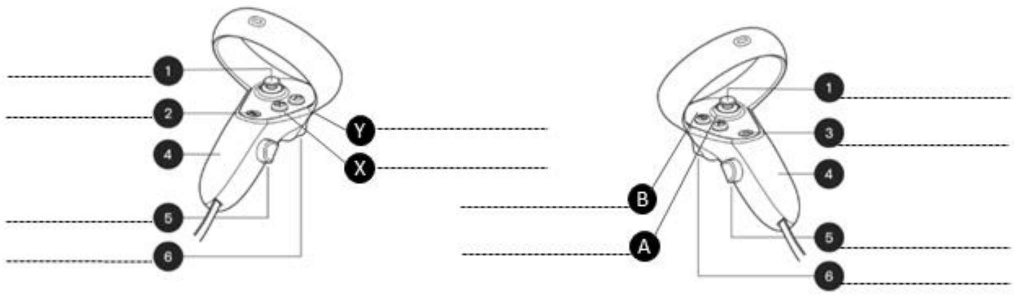
❒ 3D view (players interact with objects in the whole virtual environment)

❒ 2D view (player interact with objects in the flat screen inside the virtual environment)



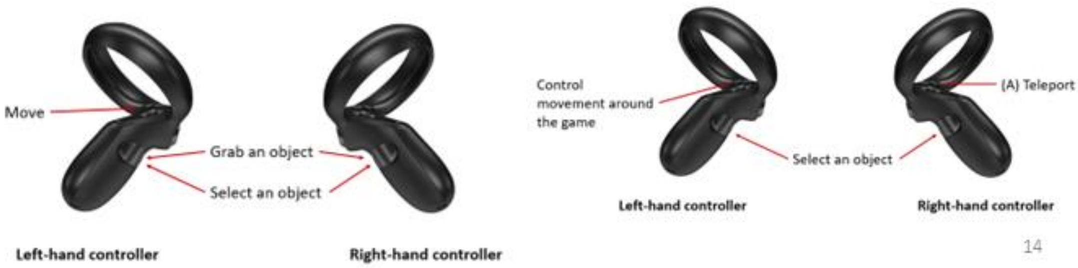
Controller mapping (specify function)

Left hand controller **Right hand controller**



1. Thumbsticks 2. Menu button 3. Oculus button
4. Battery covers 5. Grip buttons 6. Triggers

Example of controller mapping



Action Design (cont.)

Feedback

What is feedback that the users receive from the exhibit after they interact with the exhibit ?

❒ **Visual**

❒ text ....

....

....

....

....

....

❒ image ....

....

....

....

....

....

❒animation..

....

....

....

....

....

❒ **Sound**

....

....

....

....

....

....

❒ Controller vibration

....

....

....

....

....

....

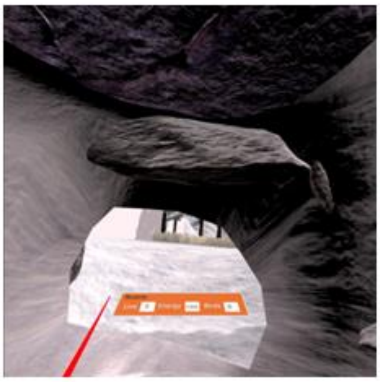
Action Design (cont.)

Example of feedback.

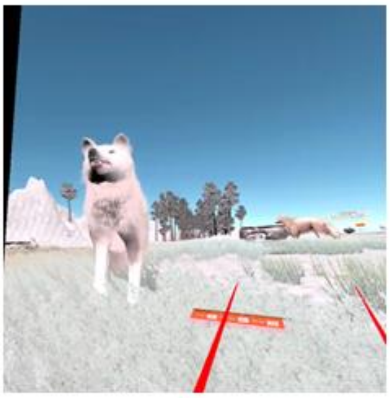
An example scene of visual feedback that can create in VE, snow a falling effect, transforming a bird into a number.

An example scene of visual effect and objects movement that can create in VE; movement of the steam engine, produce smoke, produce steam, create fire.

An example of a player is inside the cave.



An example of predator is attacking the player. The player hear the wolf's roar.



Social Interaction Design

Define factors that support players having social interaction in the VE. Having social interaction in VR via interacting with another player via the virtual body (VB), also called an avatar.

Learning Approach

Define how the exhibit provides visitors with the opportunity to access the VR exhibit simultaneously.

❒ **Constructivism** (single player, a player construct knowledge by themselves by interacting with the exhibit)

....

....

....

....

❒ **Sociocultural** (the exhibit design that provides for people to have social interaction during their experience with the VR exhibit. Visitors have a discussion and learn from each other)

❒ Co-presence (a player interactive with the exhibit while allow other visitors observing the player play with the exhibit)

....

....

....

....

❒ Co-player (the VR exhibit allows more than one player to play the exhibit together and help each other achieve the exhibit's goal)

....

....

....

....

❒ Competition (the VR exhibit allows more than one player to interact with the exhibit, and the player competes with other players to achieve the exhibit's goal)

....

....

....

....

Social Interaction Design (cont.)

Communication

Define communication features for players communicate and discuss in the VE. A player can communicate with other players by conversation and use a pointer to indicate the object in the conversation.

❒ **Conversation**

voice setup

❒ same volume all distance

❒ according to distance between player

distance..

minimum volume ....

❒ **Pointing object**

ray pointer

- normal

colour...

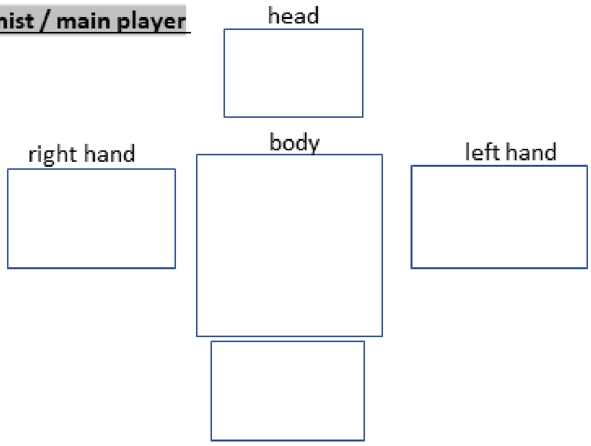
- hit interactable object

colour...................

Avatar representation

Design appearance of an avatar to represent a player in virtual environment.

Protagonist / main player



Where the position of ray beam out?

❒ hand

❒ left ❒ right

❒ body

❒ head

Other players avatar

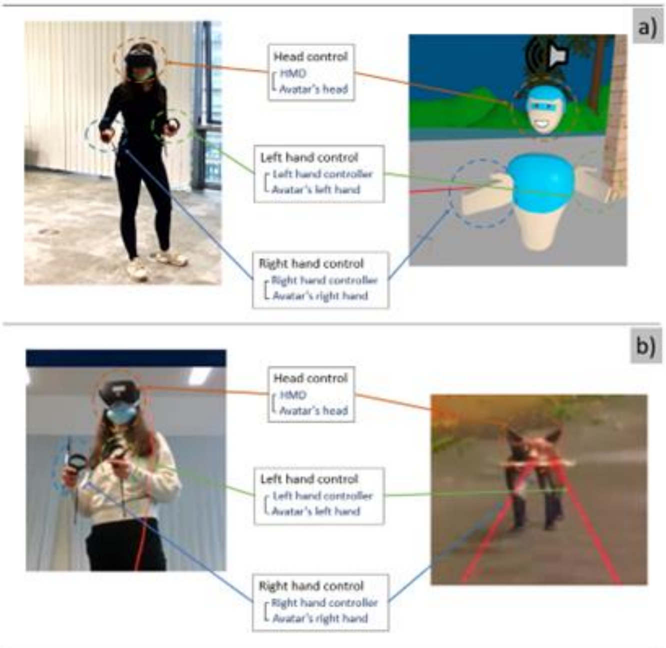
(draw other avatar player in case have more than one character to represent players

Social Interaction Design (cont.)

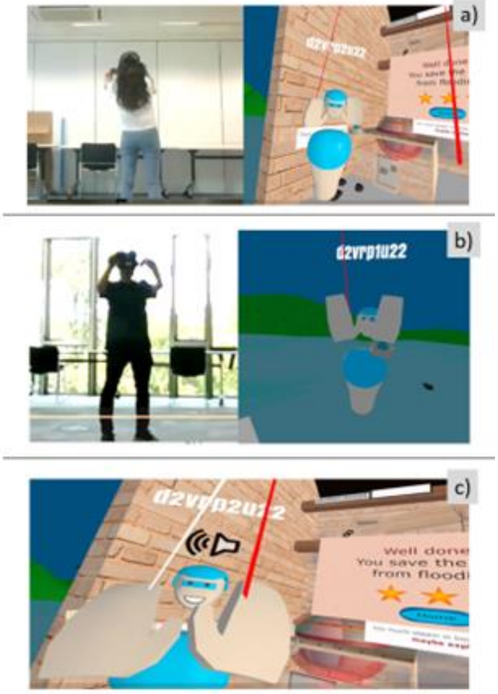
Example of the avatar and social interaction in virtual environment.

Example of avatar presentation player in VE and show mapping diagram between a player and an avatar. a) show an avatar in the case that has the head, left hand and right hand to represent the player. b) show an avatar in the case without visually representing hands.

Mapping diagram between a player and an avatar.



An example of avatar movement synchronising with player movement and an example of social interaction in VE. a) Player 1 and avatar represent Player 1 in VE. b) Player 2 and avatar represent Player 2 in VE. c) social interaction between Player 1 and Player 2 and their avatar in VE.



An example of ray pointer.

System Design

System design refers to the control features of the VR exhibit system. It focus on software of the VR system.

System structure

Define the flow of the system. The sequence of experiences that the designer intends for visitors to interact with the exhibit. The flow of the system can be linear or dependent on the condition.

❒ linear (visitors experience content of the exhibit step by step)

❒ Depended on condition (visitors has the choice to select which one they want to play)

Flow chart (draw a flow chart to explain the system)

System Design (cont.)

VR HMD device

Define the HMD device and tracking system that you intend to use.

Device type

❒ wire

Name of the Headset

❒ wireless

Name of the Headset

Tracking System

Install and open exhibit system (software of the system)

Define how to install the system software, and how to open and close the system daily.

How to install software of the VR exhibit? (install the system software of exhibit)

How to open the system of the VR exhibit? (open the system software of exhibit)

How to close the system of the VR exhibit? (close the system software of exhibit)

Reset system

How to reset the system back to the start/home page?

When will the system restart?

Safety and health

Define the safety and health factors that need to concern when visitors using the VR exhibit.

Device management

Where is the place to put the VR HMD?

How to provide the power for VR HMD and controller?

How to clean the VR HMD (face covering mask) for the next visitor ?

Staff management

Do the exhibit need staff to support during visitor play with the exhibit?

❒ Yes How many staff ?

________people

❒ No

What are tasks that intend floor staff to support?

Visitor management

How to manage visitor have an experience with the VR exhibit?

■ Normal situation

■ Crowded situation

- How to manage queue

- How long in the maximum that allow a visitor play the VR exhibit?

Safety and health (cont.)

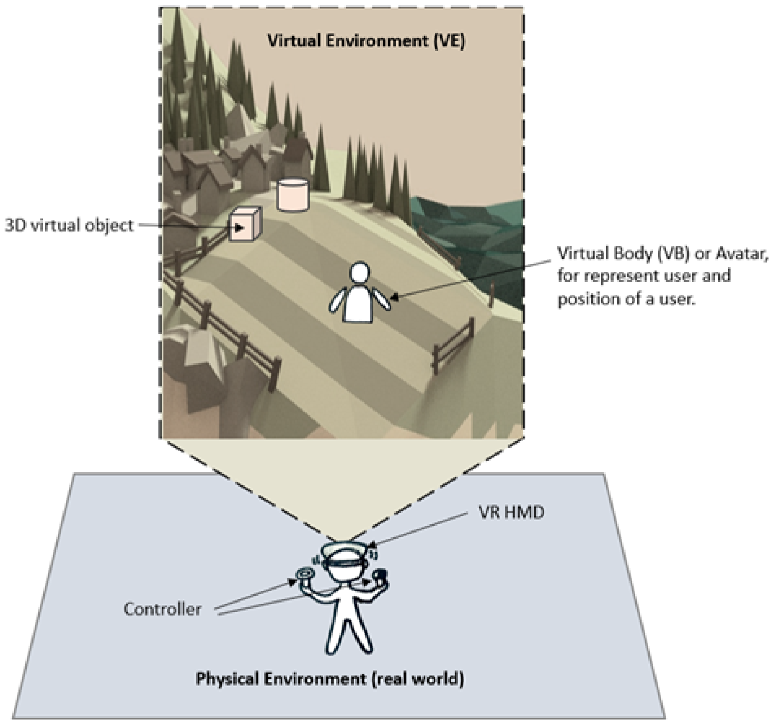
Area management

Where is the area for play the VR?

How is big?

Plan for set up the VR exhibit (draw overview how to display the exhibit)

VR HMD experience overview



A player is wearing the VR HMD and holding the VR controllers while standing in the physical world (real world). The HMD will display a simulation of the virtual environment, and the virtual environment surrounds the player. The system allows the player to turn their physical head and body to look around the VE. At the same time, the physical body of a player moves the virtual body (VB, also called an avatar) that is used to represent a player in the VE, and which may move according to the player 's physical body, head and hands. The VB can move to synchronize with the physical body, facilitated by a system which tracks the position and rotation of the headset and the controllers. The player may be able interact with 3D virtual objects by pressing a button on the controller to provoke an action. The feedback can be visual feedback, which changes the VE, audio feedback, or haptic feedback, as some controllers can generate vibration.

It can discuss HMD VR systems into five parts: input part, virtual environment, interaction, output device, and control system. The input part includes the headset, the controller, and the tracking system. The virtual environment is the visual simulation displayed for players to experience which can have interactable and static 3D virtual objects. The interaction part describes how players interact with the VE and how they move and navigate within the VE. The output part provides feedback to players, normally visual feedback through the HMD and audio feedback through an embedded speaker on the HMD. The control system manages the input and output of the system. It processes input data to respond to users when they interact with the system.

Appendix B Study One questionnaire

Alternative design for an interactive exhibit experiment.

Alternative design for an interactive exhibit User ID:

User ID: ……………………………………
Type of Interface: ……………………
Date: ………………………………………

Study title: Alternative design for an interactive exhibit

(before play with an interactive exhibit)

User background experience

1. Gender

☐ male ☐ female ☐ others

2. Have you ever visited the Science and Technology museums before?

☐ Yes. Name of museum: ☐ No

3. Do you have the experience to play with gesture interface before such as Kinect?

☐ Yes. ☐ No

4. Do you have the experience to play with tangible interface before like an example below?

☐ Yes. ☐ No


5. Do you have the experience to play with VR technology before like an example below?

☐ Yes. ☐ No

6. Do you have previous knowledge about poisonous mushrooms or frogs?

☐ Yes. ☐ No

(after have an experience with an interactive exhibit)

Please make your evaluation now.

For the assessment of the product (interactive exhibit), please fill out the following questionnaire. The questionnaire consists of pairs of contrasting attributes that may apply to the product (interactive exhibit). The circles between the attributes represent gradations between the opposites. You can express your agreement with the attributes by ticking the circle that most closely reflects your impression.

Example:

attractive	○	⊗	○	○	○	○	○	unattractive

This response would mean that you rate the application as more attractive than unattractive.

Please decide spontaneously. Don't think too long about your decision to make sure that you convey your original impression.

Sometimes you may not be completely sure about your agreement with a particular attribute or you may find that the attribute does not apply completely to the particular product. Nevertheless, please tick a circle in every line.

It is your personal opinion that counts. Please remember: there is no wrong or right answer!

Alternative design for an interactive exhibit User ID:

Exhibit 1: Gesture

Please assess the product: Exhibit 1 Gesture now by ticking one circle per line.

	1	2	3	4	5	6	7		
annoying	O	O	O	O	O	O	O	enjoyable	1
not understandable	O	O	O	O	O	O	O	understandable	2
creative	O	O	O	O	O	O	O	dull	3
easy to learn	O	O	O	O	O	O	O	difficult to learn	4
valuable	O	O	O	O	O	O	O	inferior	5
boring	O	O	O	O	O	O	O	exciting	6
not interesting	O	O	O	O	O	O	O	interesting	7
unpredictable	O	O	O	O	O	O	O	predictable	8
fast	O	O	O	O	O	O	O	slow	9
inventive	O	O	O	O	O	O	O	conventional	10
obstructive	O	O	O	O	O	O	O	supportive	11
good	O	O	O	O	O	O	O	bad	12
complicated	O	O	O	O	O	O	O	easy	13
unlikable	O	O	O	O	O	O	O	pleasing	14
usual	O	O	O	O	O	O	O	leading edge	15
unpleasant	O	O	O	O	O	O	O	pleasant	16
secure	O	O	O	O	O	O	O	not secure	17
motivating	O	O	O	O	O	O	O	demotivating	18
meets expectations	O	O	O	O	O	O	O	does not meet expectations	19
inefficient	O	O	O	O	O	O	O	efficient	20
clear	O	O	O	O	O	O	O	confusing	21
impractical	O	O	O	O	O	O	O	practical	22
organized	O	O	O	O	O	O	O	cluttered	23
attractive	O	O	O	O	O	O	O	unattractive	24
friendly	O	O	O	O	O	O	O	unfriendly	25
conservative	O	O	O	O	O	O	O	innovative	26

Alternative design for an interactive exhibit User ID:

Exhibit 1: Gesture

Please tell us more about your experience after play with the interactive exhibit

27. Which feature do you like in this interactive exhibit?

28. Which feature do you want to improve this interactive exhibit?

29. What do you learn from this interactive exhibit?

 29a. About scientific content (what the message that you take from the exhibit)

 19b. About the feedback from the exhibit (sound, colour, animation)

30. Other recommendations?

Alternative design for an interactive exhibit User ID:

Exhibit 2: Tangible

Please assess the product: Exhibit 2 Tangible now by ticking one circle per line.

	1	2	3	4	5	6	7		
annoying	○	○	○	○	○	○	○	enjoyable	1
not understandable	○	○	○	○	○	○	○	understandable	2
creative	○	○	○	○	○	○	○	dull	3
easy to learn	○	○	○	○	○	○	○	difficult to learn	4
valuable	○	○	○	○	○	○	○	inferior	5
boring	○	○	○	○	○	○	○	exciting	6
not interesting	○	○	○	○	○	○	○	interesting	7
unpredictable	○	○	○	○	○	○	○	predictable	8
fast	○	○	○	○	○	○	○	slow	9
inventive	○	○	○	○	○	○	○	conventional	10
obstructive	○	○	○	○	○	○	○	supportive	11
good	○	○	○	○	○	○	○	bad	12
complicated	○	○	○	○	○	○	○	easy	13
unlikable	○	○	○	○	○	○	○	pleasing	14
usual	○	○	○	○	○	○	○	leading edge	15
unpleasant	○	○	○	○	○	○	○	pleasant	16
secure	○	○	○	○	○	○	○	not secure	17
motivating	○	○	○	○	○	○	○	demotivating	18
meets expectations	○	○	○	○	○	○	○	does not meet expectations	19
inefficient	○	○	○	○	○	○	○	efficient	20
clear	○	○	○	○	○	○	○	confusing	21
impractical	○	○	○	○	○	○	○	practical	22
organized	○	○	○	○	○	○	○	cluttered	23
attractive	○	○	○	○	○	○	○	unattractive	24
friendly	○	○	○	○	○	○	○	unfriendly	25
conservative	○	○	○	○	○	○	○	innovative	26

Alternative design for an interactive exhibit User ID:

Exhibit 2: Tangible

Please tell us more about your experience after play with the interactive exhibit

27. Which feature do you like in this interactive exhibit?

28. Which feature do you want to improve this interactive exhibit?

29. What do you learn from this interactive exhibit?

    29a. About scientific content (what the message that you take from the exhibit)

    19b. About the feedback from the exhibit (sound, colour, animation)

30. Other recommendations?

Alternative design for an interactive exhibit User ID:

Exhibit 3: VR

Please assess the product: Exhibit 3 VR now by ticking one circle per line.

	1	2	3	4	5	6	7		
annoying	○	○	○	○	○	○	○	enjoyable	1
not understandable	○	○	○	○	○	○	○	understandable	2
creative	○	○	○	○	○	○	○	dull	3
easy to learn	○	○	○	○	○	○	○	difficult to learn	4
valuable	○	○	○	○	○	○	○	inferior	5
boring	○	○	○	○	○	○	○	exciting	6
not interesting	○	○	○	○	○	○	○	interesting	7
unpredictable	○	○	○	○	○	○	○	predictable	8
fast	○	○	○	○	○	○	○	slow	9
inventive	○	○	○	○	○	○	○	conventional	10
obstructive	○	○	○	○	○	○	○	supportive	11
good	○	○	○	○	○	○	○	bad	12
complicated	○	○	○	○	○	○	○	easy	13
unlikable	○	○	○	○	○	○	○	pleasing	14
usual	○	○	○	○	○	○	○	leading edge	15
unpleasant	○	○	○	○	○	○	○	pleasant	16
secure	○	○	○	○	○	○	○	not secure	17
motivating	○	○	○	○	○	○	○	demotivating	18
meets expectations	○	○	○	○	○	○	○	does not meet expectations	19
inefficient	○	○	○	○	○	○	○	efficient	20
clear	○	○	○	○	○	○	○	confusing	21
impractical	○	○	○	○	○	○	○	practical	22
organized	○	○	○	○	○	○	○	cluttered	23
attractive	○	○	○	○	○	○	○	unattractive	24
friendly	○	○	○	○	○	○	○	unfriendly	25
conservative	○	○	○	○	○	○	○	innovative	26

Alternative design for an interactive exhibit User ID:

Exhibit 3: VR

Please tell us more about your experience after play with the interactive exhibit

27. Which feature do you like in this interactive exhibit?

28. Which feature do you want to improve this interactive exhibit?

29. What do you learn from this interactive exhibit?

  29a. About scientific content (what the message that you take from the exhibit)

  19b. About the feedback from the exhibit (sound, colour, animation)

30. Other recommendations?

Appendix C Study Two questionnaire

Social interaction design in VR for museums experiment.

ID:

Study two Questionnaire: Social interaction in VR for museums

(before play with an interactive exhibit)
Part 1: User background experience

1. Gender

☐ male ☐ female ☐ others

2. Have you ever visited the Science and Technology museums before?

☐ Yes, name of museum: .... ☐ No

3. How often do you visit museum?
- ☐ At least once a day
- ☐ At least three times per week
- ☐ At least once a week
- ☐ At least once every 15 days
- ☐ Rarely
- ☐ Never

4. How often do you visit exhibition online on website?
- ☐ At least once a day
- ☐ At least three times per week
- ☐ At least once a week
- ☐ At least once every 15 days
- ☐ Rarely
- ☐ Never

5. How often do you play with VR technology?
- ☐ At least once a day
- ☐ At least three times per week
- ☐ At least once a week
- ☐ At least once every 15 days
- ☐ Rarely
- ☐ Never

6. How often do you use mouse and keyboard to working with computer?
- ☐ At least once a day
- ☐ At least three times per week
- ☐ At least once a week
- ☐ At least once every 15 days
- ☐ Rarely
- ☐ Never

ID:

(After have an experience with each interactive exhibit)
Part 2: self-report questionnaire on experiencing with each interactive exhibit.

Design case

Items (Positive Sentence)	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1. I had a sense of being there in the exhibit rather than I saw the exhibit.					
2. I have a limited to move around inside the virtual exhibit.					
3. I feel the visual aspect of the virtual exhibit involve me.					
4. I feel the audio aspect of the virtual exhibit involve me.					
5. I did not perceive my body in the virtual exhibit environment.					
6 I naturally interact with the object in the virtual exhibit.					
7. I feel my partner did not perceive me.					
8. I aware of my partner in the virtual exhibit.					
9. I feel alone in the virtual exhibit.					
10. I felt my partner seem alive in the virtual exhibit. (VB real)					
11. My partner did not understand what I meant when I say.					
12. My partner understood correctly the object that I told. (pointing, directing an object).					
13. I did perceive my partner emotion.					
14. I felt bored play with the exhibit.					
15. I felt engaged with the exhibit.					
16. I gain some knowledge from my partner during I play the exhibit.					
17. My partner interrupt me to learn from the exhibit.					

ID:

Please tell us more about your experience after play with this interactive exhibit.
(Interview question of overall experience and issue using each interactive exhibit.)

1. How is it easy or difficult for you to play with this interactive exhibit (e.g. movement, pointing object, grab an object, communication)
   P1:
   P2:

2. Do you have any problem during play with this interactive exhibit?
   P1:
   P2:

3. Do the virtual body in the virtual word is important for you when you play this exhibit.

ID:

Design case

Items (Positive Sentence)	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1. I had a sense of being there in the exhibit rather than I saw the exhibit.					
2. I have a limited to move around inside the virtual exhibit.					
3. I feel the visual aspect of the virtual exhibit involve me.					
4. I feel the audio aspect of the virtual exhibit involve me.					
5. I did not perceive my body in the virtual exhibit environment.					
6 I naturally interact with the object in the virtual exhibit.					
7. I feel my partner did not perceive me.					
8. I aware of my partner in the virtual exhibit.					
9. I feel alone in the virtual exhibit.					
10. I felt my partner seem alive in the virtual exhibit. (VB real)					
11. My partner did not understand what I meant when I say.					
12. My partner understood correctly the object that I told. (pointing, directing an object).					
13. I did perceive my partner emotion.					
14. I felt bored play with the exhibit.					
15. I felt engaged with the exhibit.					
16. I gain some knowledge from my partner during I play the exhibit.					
17. My partner interrupt me to learn from the exhibit.					

ID:

Please tell us more about your experience after play with this interactive exhibit.
(Interview question of overall experience and issue using each interactive exhibit.)

1. How is it easy or difficult for you to play with this interactive exhibit (e.g. movement, pointing object, grab an object, communication)
   P1:
   P2:

2. Do you have any problem during play with this interactive exhibit?
   P1:
   P2:

3. Do the virtual body in the virtual word is important for you when you play this exhibit.

ID:

Design case

Items (Positive Sentence)	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1. I had a sense of being there in the exhibit rather than I saw the exhibit.					
2. I have a limited to move around inside the virtual exhibit.					
3. I feel the visual aspect of the virtual exhibit involve me.					
4. I feel the audio aspect of the virtual exhibit involve me.					
5. I did not perceive my body in the virtual exhibit environment.					
6 I naturally interact with the object in the virtual exhibit.					
7. I feel my partner did not perceive me.					
8. I aware of my partner in the virtual exhibit.					
9. I feel alone in the virtual exhibit.					
10. I felt my partner seem alive in the virtual exhibit. (VB real)					
11. My partner did not understand what I meant when I say.					
12. My partner understood correctly the object that I told. (pointing, directing an object).					
13. I did perceive my partner emotion.					
14. I felt bored play with the exhibit.					
15. I felt engaged with the exhibit.					
16. I gain some knowledge from my partner during I play the exhibit.					
17. My partner interrupt me to learn from the exhibit.					

ID:

Please tell us more about your experience after play with this interactive exhibit.
(Interview question of overall experience and issue using each interactive exhibit.)

1. How is it easy or difficult for you to play with this interactive exhibit (e.g. movement, pointing object, grab an object, communication)
   P1:
   P2:

2. Do you have any problem during play with this interactive exhibit?
   P1:
   P2:

3. Do the virtual body in the virtual word is important for you when you play this exhibit.

ID:

(After have experience with all interactive exhibits)
Please tell us more about your experience after play with all interactive exhibit.

Part 3: Overall experience

1. Which design of interactive exhibit do you prefer for play with your friend?

2. Which features do you like in the design of the interactive exhibit?

3. Is the visual information (text, animation) in the interactive exhibit is clear for you to read?

4. Is the sound information in the interactive exhibit is clear for you?

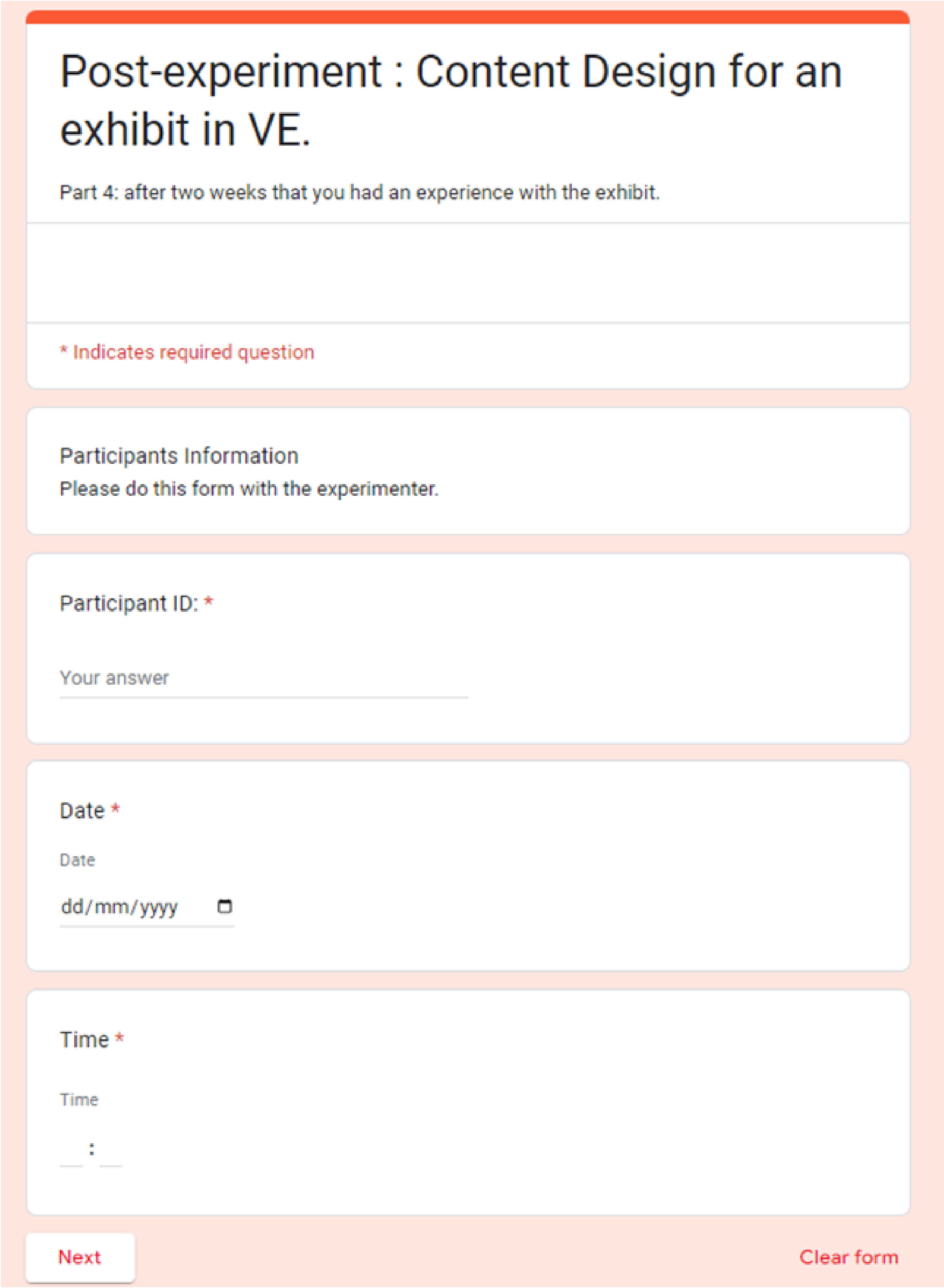
5. Is the layout, size and position of the object in the game (virtual environment) appropriate design? (e.g. too high or too low, too big or small).

6. Which virtual body (VB) feature helped you understand what your partner said?
   - Facial expression
   - Gesture (waving hand, pointer)
   - Eye contact
   - Body movement
   - Voice

8. Which the game style that you like for this exhibit, and why?
   - **Exploration**, explore each part of steam engine.
   - **Quiz**, question and Answer.
   - **Explanation**, explain how the steam engine work.
   - **Complete a mission**, the mission pump the water from the mine.

7. Other recommendations?

After two weeks experiment (online questionnaire)



Post-experiment : Content Design for an exhibit in VE.

Part 4: after two weeks that you had an experience with the exhibit.

* Indicates required question

Participants Information

Please do this form with the experimenter.

Participant ID: *

Your answer

Date *

Date

dd/mm/yyyy

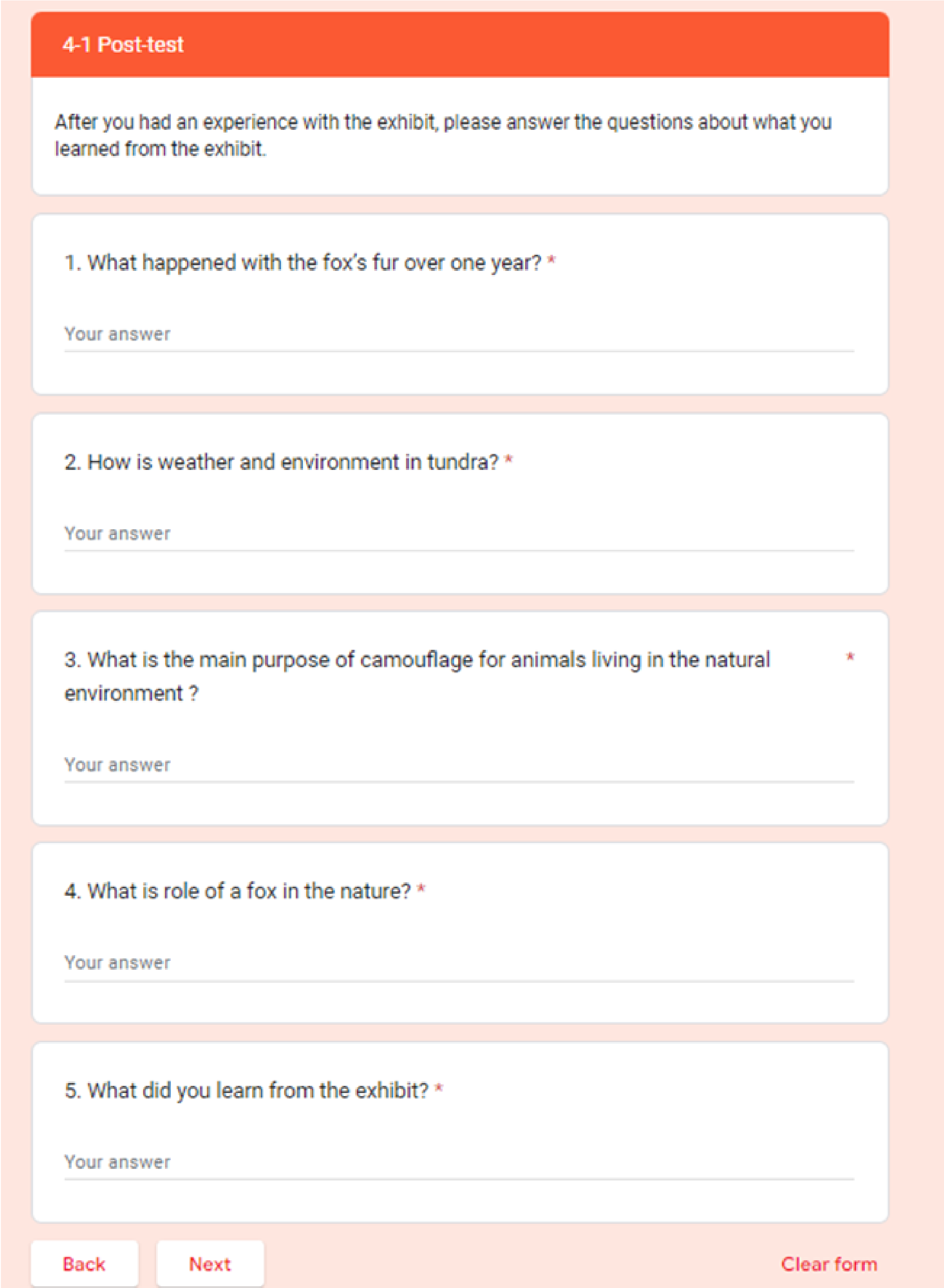
Time *

Time

:

Next

Clear form



4-1 Post-test

After you had an experience with the exhibit, please answer the questions about what you learned from the exhibit.

1. What happened with the fox's fur over one year? *

Your answer

2. How is weather and environment in tundra? *

Your answer

3. What is the main purpose of camouflage for animals living in the natural environment ? *

Your answer

4. What is role of a fox in the nature? *

Your answer

5. What did you learn from the exhibit? *

Your answer

Back Next Clear form

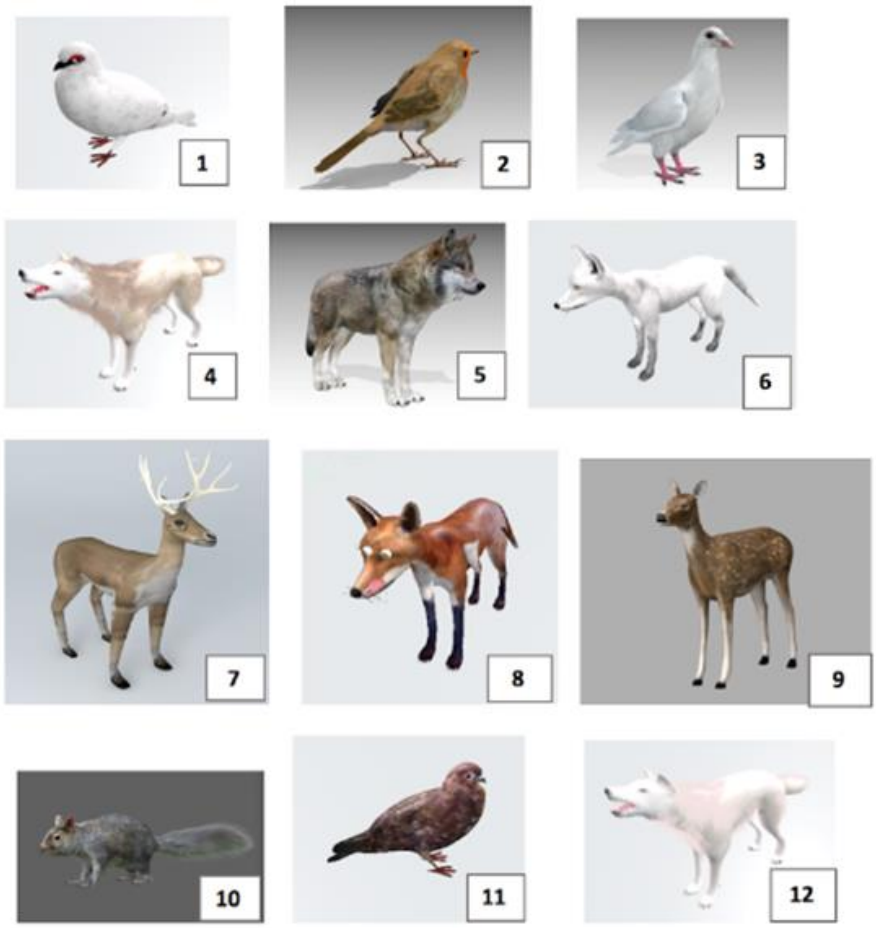
4-2 Memory test

After 2 weeks that you have an experience with the game in the exhibit, please tell us how much you can remember the story in the game.

1. Please describe the story that you have the experience with the exhibit?(whole story). The experimenter will interview you for this question.

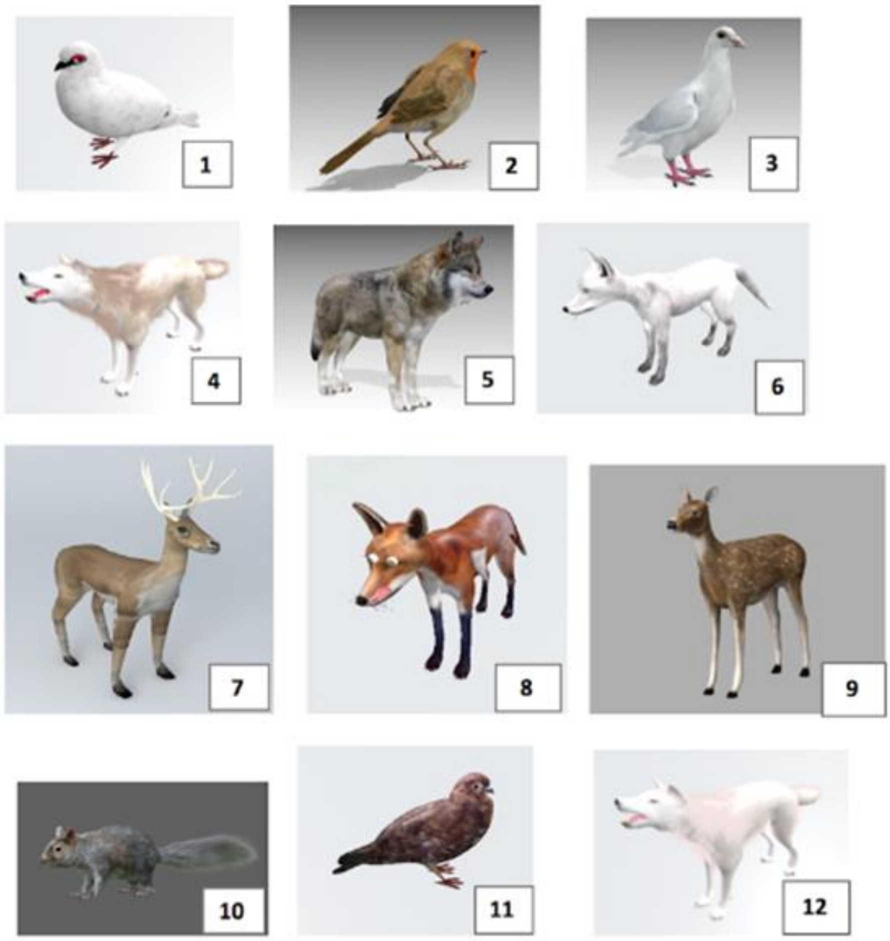
Your answer

2. What is the character of the bird in the story in winter? (Please answer the question by write the numbers of the animal that you want to answer. *



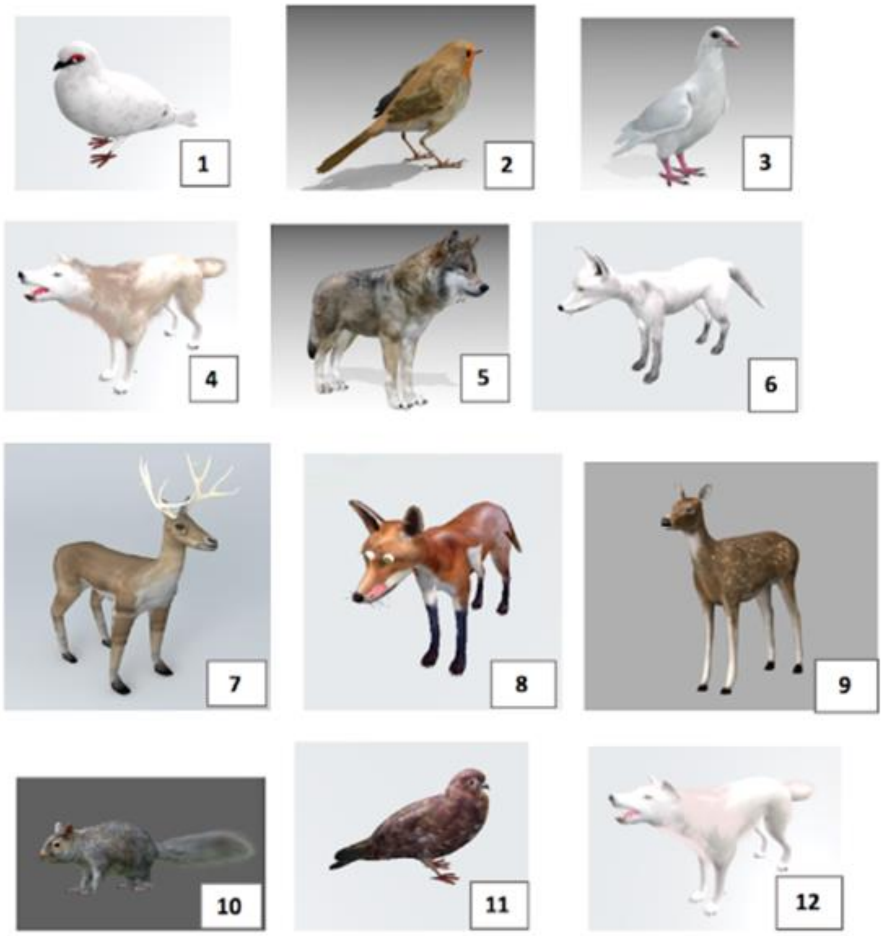
Your answer

3. Which of the following are animal in the story? (Please answer the question by write the numbers of the animal that you want to answer.) *



Your answer

4. What is the character of the fox in summer? (Please answer the question by write the numbers of the animal that you want to answer.) *



Your answer

5. What is the name of bird in the story? *

- ◯ Kittiwake
- ◯ Sanderling
- ◯ Ptarmigan

6. Which animal hunt fox as his food in the story? *

- ◯ lion
- ◯ wolves
- ◯ tiger

7. Where the area that the fox can hide in the story? (please explain) *

Your answer

Back Next Clear form

Submit the answer

Participants ID *

Your answer

Submit Date *

Date

dd/mm/yyyy

Submit Time *

Time

:

Back Submit Clear form

Appendix D Study Three questionnaire

Content design of an exhibit in VE experiment

Pre and Post experiment

User ID:

Study Three: Content Design for an exhibit in VE.

Part 1: General Information, please tell us more about yourself.

Please answer the question by ✓

1. Gender

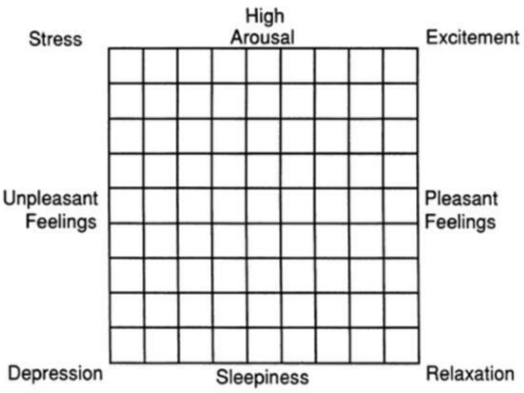
☐ male ☐ female ☐ others

2. How often do you play with VR technology?
   - ☐ At least once a day
   - ☐ At least three times per week
   - ☐ At least once a week
   - ☐ At least once every 15 days
   - ☐ Rarely
   - ☐ Never

3. Please range which media help your learn a new thing the most (1-3)

___text __ Audio __Picture

4. How is your feeling today? Please ✓ to select one that represent you emotion today.



User ID:

Part 2: Pre-test

Before you experience the exhibit, please answer the questions based on your background knowledge about camouflage.

1. What is the main purpose of camouflage for animals living in the natural environment ?

2. What is role of a fox in nature?

3. What happens with a fox's fur over one year?

4. How is weather and environment in the tundra?

User ID:

Part 3: after had an experience with the exhibit.
3-1 Post-test

After you had an experience with the exhibit, please answer the questions about what you learned from the exhibit.

1. What is the main purpose of camouflage for animals living in the natural environment ?

2. What is role of a fox in the nature?

3. What happens with the fox's fur over one year?

4. How is weather and environment in tundra?

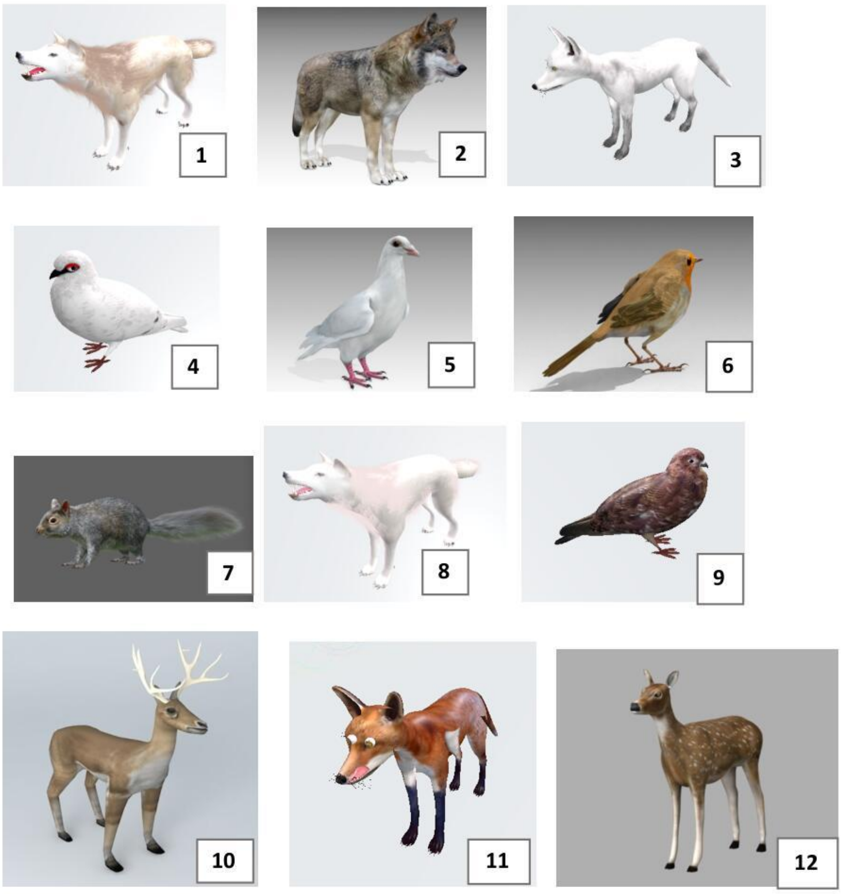
User ID:

3-2 Memory test

After you have an experience with the game in the exhibit, please tell us how much you can remember the story in the game.

1. Please describe the story that you have the experience with the exhibit? (whole story). The experimenter will interview you for this question.

Use the following pictures answer the question 2-4



User ID:

Please answer the question by ✓ the number of the animal that you want to answer.

2. Which of the following are animal in the story?

____1 ____2 ____3 ____4 ____5 ____6

____7 ____8 ____9 ____10 ____11 ____12

3. What is the character of the fox in summer?

____1 ____2 ____3 ____4 ____5 ____6

____7 ____8 ____9 ____10 ____11 ____12

4. What is the character of the bird in the story in winter?

____1 ____2 ____3 ____4 ____5 ____6

____7 ____8 ____9 ____10 ____11 ____12

5. Where the area that the fox can hide in the story? (please explain)

6. Which animal hunt fox as his food in the story?

☐ wolves ☐ lion ☐ tiger

7. What is the name of bird in the story?

☐ Ptarmigan ☐ Kittiwake ☐ Sanderling

User ID:

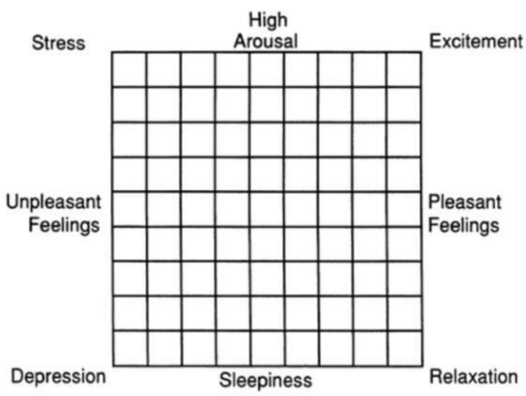
3-3 Immersion

Please tell us more about your experience with the exhibit by ✓ the answer that represent you experience on each question.

Questions	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1. I had a sense of being there in the exhibit rather than I saw the exhibit.					
2. I have a high degree of freedom to move around inside the virtual exhibit.					
3. I feel the visual aspect of the virtual exhibit involve me.					
4. I feel the audio aspect of the virtual exhibit involve me.					
5. I perceive my body in the virtual exhibit environment.					
6. I naturally interact with the object in the virtual exhibit.					

3-4 Emotion

1. How do you feel after playing the game? Please ✓ select the one that best describes your feeling.



User ID:

2. Please score how is the game effect on your emotion.

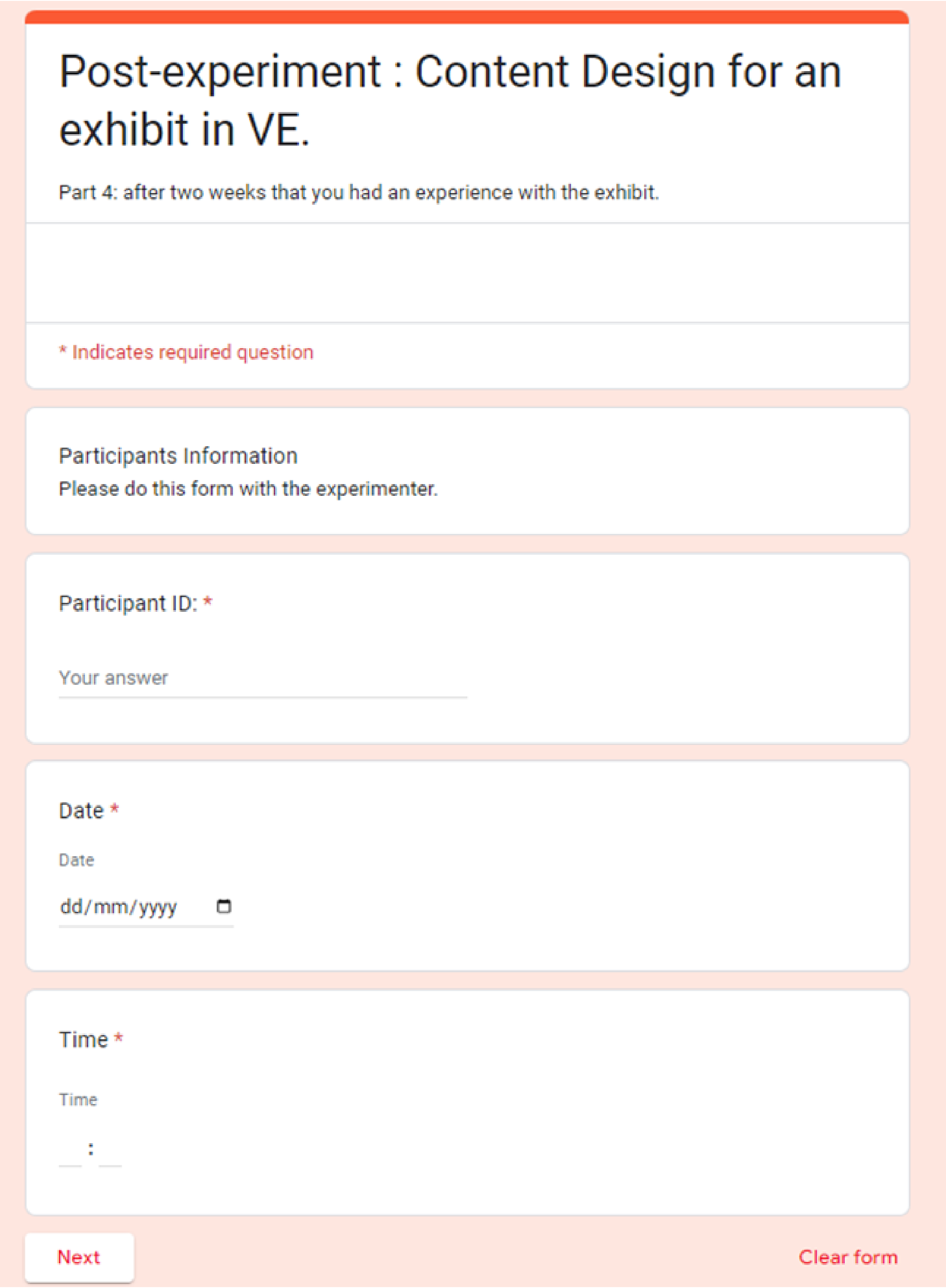
1	2	3	4	5
Very Slightly or Not at all	**A Little**	**Moderately**	**Quite a Bit**	**Extremely**

____1. Interested
____2. Distressed
____3. Excited
____4. Upset
____5. Strong
____6. Guilty
____7. Scared
____8. Hostile
____9. Enthusiastic
____10. Proud
____11. Irritable
____12. Alert
____13. Ashamed
____14. Inspired
____15. Nervous
____16. Determined
____17. Attentive
____18. Jittery
____19. Active
____20. Afraid

3. Do you feel unwell after play the exhibit

☐ No ☐ Yes, how do you feel?..

After two weeks experiment (Online form)



Post-experiment : Content Design for an exhibit in VE.

Part 4: after two weeks that you had an experience with the exhibit.

* Indicates required question

Participants Information

Please do this form with the experimenter.

Participant ID: *

Your answer

Date *

Date

dd/mm/yyyy

Time *

Time

:

Next

Clear form

4-1 Post-test

After you had an experience with the exhibit, please answer the questions about what you learned from the exhibit.

1. What happened with the fox's fur over one year? *

Your answer

2. How is weather and environment in tundra? *

Your answer

3. What is the main purpose of camouflage for animals living in the natural environment ? *

Your answer

4. What is role of a fox in the nature? *

Your answer

5. What did you learn from the exhibit? *

Your answer

Back Next Clear form

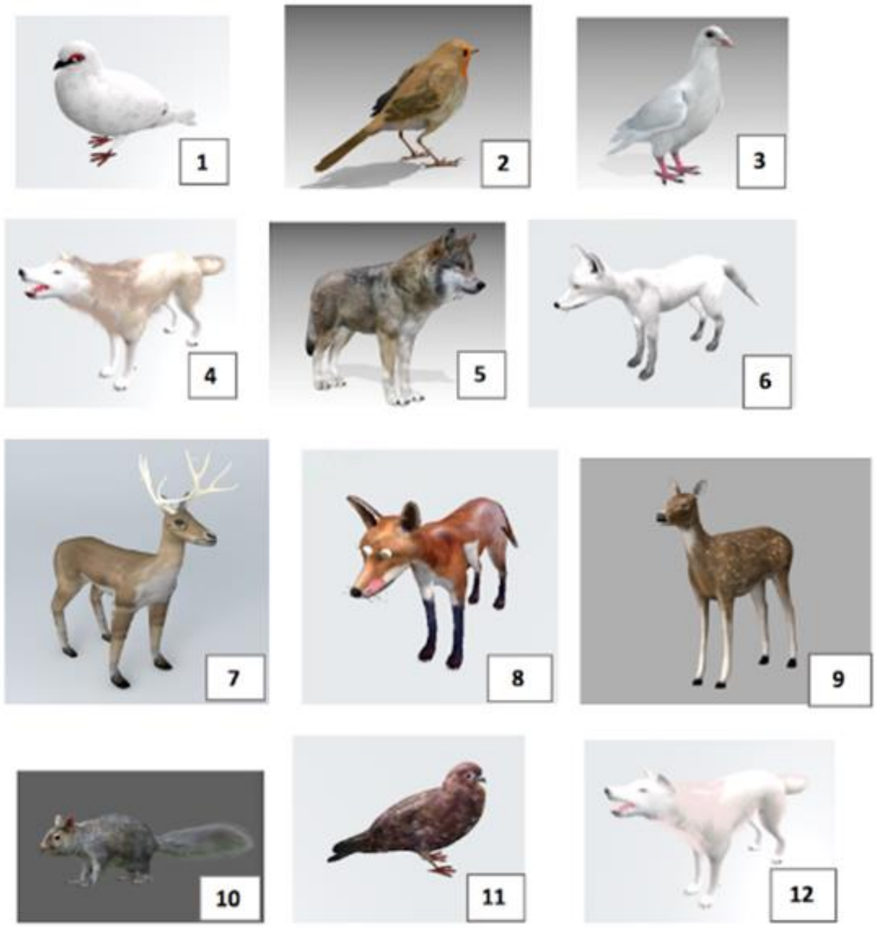
4-2 Memory test

After 2 weeks that you have an experience with the game in the exhibit, please tell us how much you can remember the story in the game.

1. Please describe the story that you have the experience with the exhibit?(whole story). The experimenter will interview you for this question.

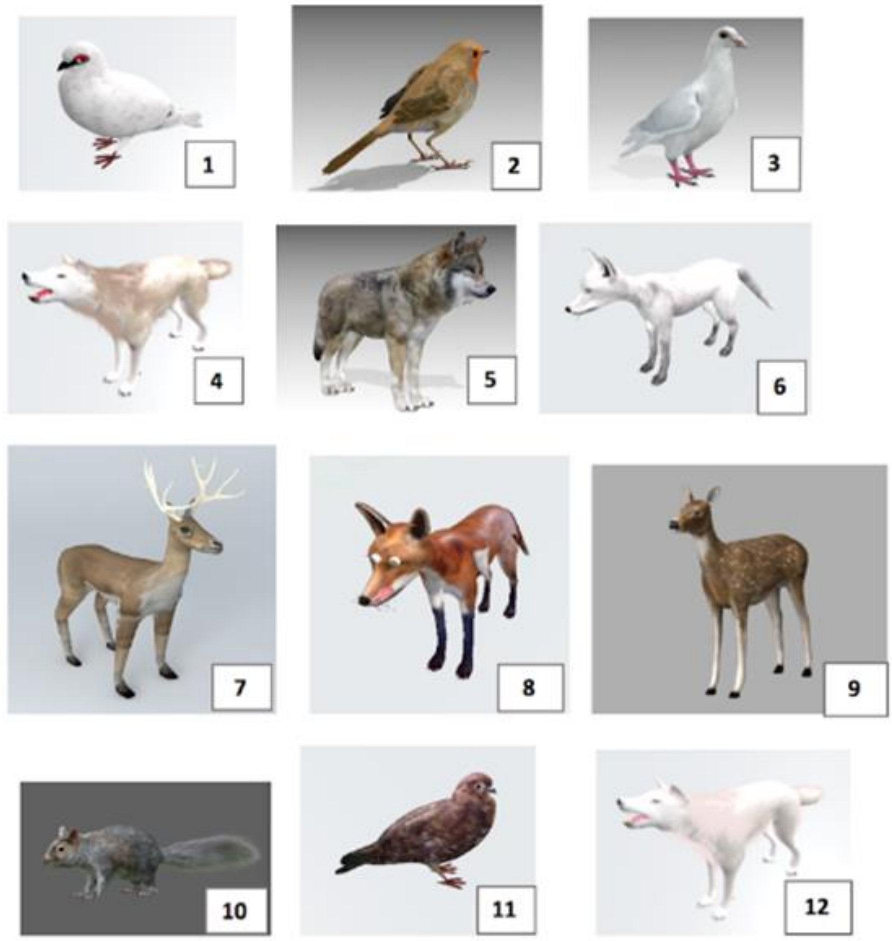
Your answer

2. What is the character of the bird in the story in winter? (Please answer the question by write the numbers of the animal that you want to answer. *



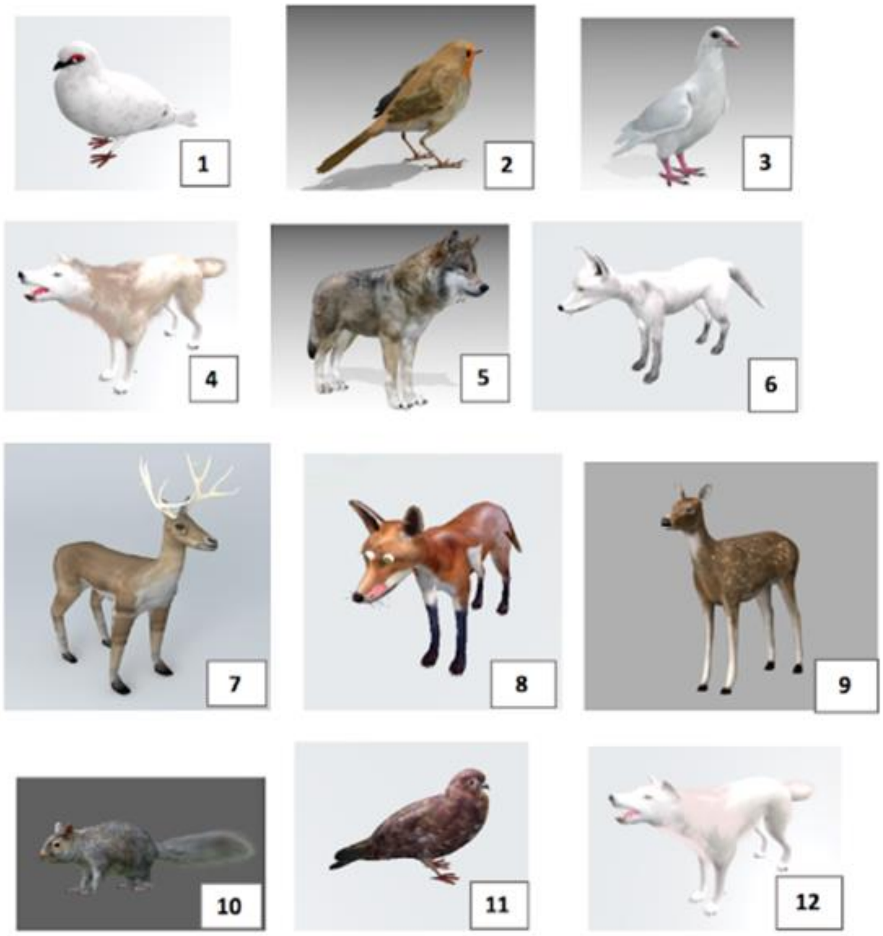
Your answer

3. Which of the following are animal in the story? (Please answer the question by write the numbers of the animal that you want to answer.) *



Your answer

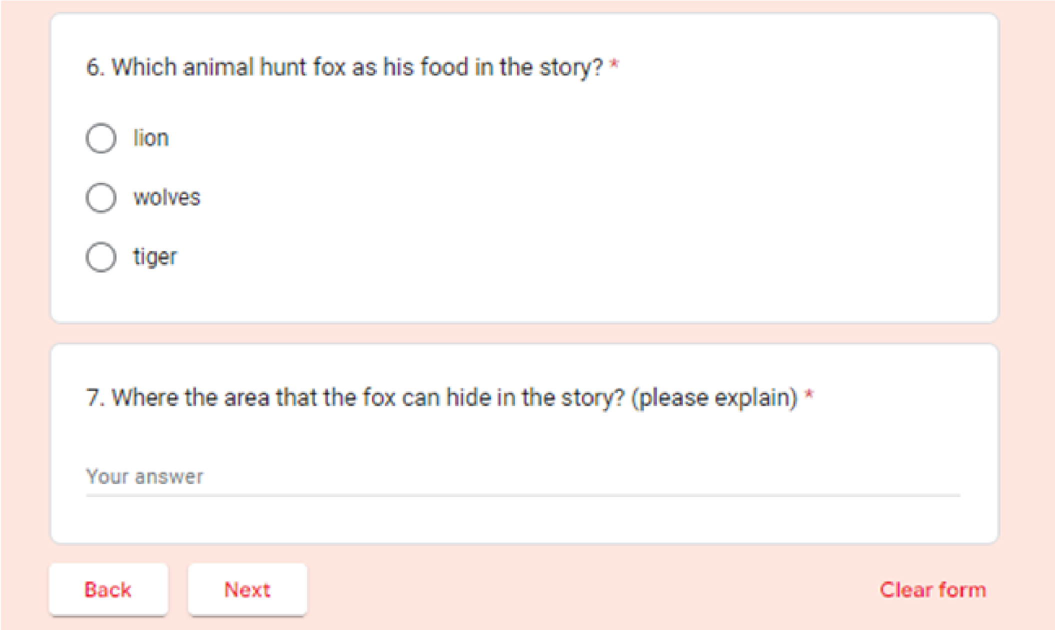
4. What is the character of the fox in summer? (Please answer the question by write the numbers of the animal that you want to answer.) *



Your answer

5. What is the name of bird in the story? *

- ○ Kittiwake
- ○ Sanderling
- ○ Ptarmigan



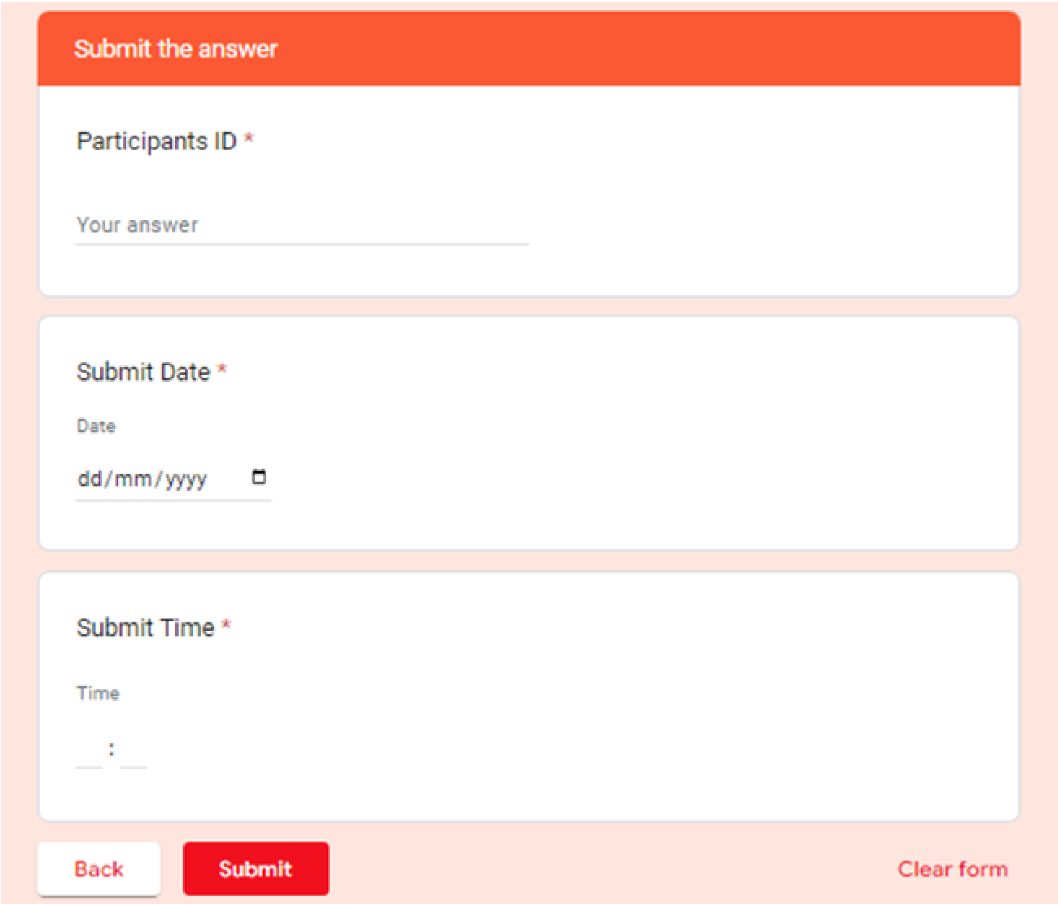
6. Which animal hunt fox as his food in the story? *

- lion
- wolves
- tiger

7. Where the area that the fox can hide in the story? (please explain) *

Your answer

Back Next Clear form



Submit the answer

Participants ID *

Your answer

Submit Date *

Date

dd/mm/yyyy

Submit Time *

Time

:

Back Submit Clear form

Appendix E Study Four questionnaire

The proposed framework evaluation

แบบสอบถามความพึงพอใจการใช้ชิ้นงาน VR

The VR exhibit system design evaluation questionnaire

ส่วนที่ 1: ข้อมูลพื้นฐาน

Part 1: User background experience

1. อายุ Age ________years

2. เพศ Gender

☐ ชาย male ☐ หญิง female

☐ ต้องการอธิบายตัวเองว่า Prefer to self-describe as ________________

☐ ไม่ประสงค์จะระบุ prefer not to say

3. คุณเล่น VR บ่อยแค่ไหน How often do you play with VR technology?

☐ หนึ่งครั้งต่อวัน At least once a day
☐ สามครั้งต่อสัปดาห์ At least three times per week
☐ หนึ่งครั้งต่อสัปดาห์ At least once a week
☐ อย่างน้อยหนึ่งครั้งทุก ๆ 15 วัน At least once every 15 days
☐ แถบจะไม่ได้เล่น Rarely
☐ ไม่เคยเล่น Never

4. คุณใช้เมาส์กับคีย์บอร์ดในการทำงานกับคอมพิวเตอร์บ่อยแค่ไหน How often do you use mouse and keyboard to working with computer?

☐ หนึ่งครั้งต่อวัน At least once a day
☐ สามครั้งต่อสัปดาห์ At least three times per week
☐ หนึ่งครั้งต่อสัปดาห์ At least once a week
☐ อย่างน้อยหนึ่งครั้งทุก ๆ 15 วัน At least once every 15 days
☐ แถบจะไม่ได้เล่น Rarely
☐ ไม่เคยเล่น Never

ส่วนที่ 2 ความพึงพอใจการใช้งานชิ้นงาน VR
Part 2: User Satisfaction Feedback

1. กรุณาระบุชิ้นงานที่คุณเล่นและต้องการประเมินเพียง 1 ชิ้นงานโดยการ ✓
Please select one of exhibits that you want to evaluate by ✓

☐ ชิ้นงาน VR เรื่องเครื่องจักรไอน้ำ

- ☐ เล่น VR คนเดียว Single player using VR
- ☐ เล่นพร้อมกันหลายคน ใช้งานแว่น VR เล่นกับแว่น VR Multi player using VR and VR
- ☐ เล่นพร้อมกันหลายคน ใช้งานแว่น VR เล่นกับคอมพิวเตอร์ Multi player using VR and PC

☐ ชิ้นงาน VR เรื่องการพรางตัว VR exhibit: Camouflage

2. ประเมินให้ระดับความพึงพอใจของคุณกับข้อคิดเห็นในแต่ละข้อโดยการ ✓
Rate your level of agreement with each statement by ✓

ประเด็นข้อคิดเห็น Statement	ไม่เห็นด้วยอย่างยิ่ง Strongly Disagree (1)	ไม่เห็นด้วย Disagree (2)	เห็นเป็นกลาง Neutral (3)	เห็นด้วย Agree (4)	เห็นด้วยอย่างยิ่ง Strongly Agree (5)
1. อุปกรณ์แว่น VR สามารถสวมใส่ง่าย The VR headset is easy to wear.					
2. อุปกรณ์แว่น VR รู้สึกสบายที่จะสวมใส่ The VR headset is comfortable to wear.					
3. อุปกรณ์ควบคุม VR (คอนโทลเลอร์) ใช้งานง่าย The VR controller is easy to use.					
4. สามารถเล่นเกมและโต้ตอบในเกมของชิ้นงานได้ง่าย The game in VR is easy to interact.					
5. สามารถที่จะเรียนรู้วิธีการเล่นเกมของชิ้นงานได้ง่าย The game is easy to understand how to interact with it.					

ประเด็นข้อคิดเห็น Statement	ไม่เห็นด้วยอย่างยิ่ง Strongly Disagree (1)	ไม่เห็นด้วย Disagree (2)	เห็นเป็นกลาง Neutral (3)	เห็นด้วย Agree (4)	เห็นด้วยอย่างยิ่ง Strongly Agree (5)
6. เกมของชิ้นงานออกแบบมาให้สามารถจดจำวิธีการเล่นการโต้ตอบกับชิ้นงานได้ง่าย The exhibit is easy to remember how to interact with it.					
7. ระยะเวลาในการเล่นเกมของชิ้นงานมีความเหมาะสม The time to play with the game completable for using VR.					
8. ชิ้นงานสามารถทำงานได้ดี ไม่เกิดปัญหาระหว่างเล่น The exhibit did not has any error during play with it.					
9. รู้สึกพอใจและประทับใจกับการเล่นชิ้นงาน I satisfied playing the VR exhibit.					
10. ชิ้นงานมีการจัดการอุปกรณ์ในการเล่นชิ้นงานได้ดี The exhibit has a well manage the VR device.					
11. ชิ้นงานมีการจัดการพื้นที่สำหรับการเล่นชิ้นงานได้ดี The exhibit has well manage the area.					
12. ชิ้นงานมีการจัดการผู้เข้าชมแต่ละคน ในการเข้าเล่นชิ้นงานได้ดี The exhibit has a well manage visitors to play with VR exhibit.					
13. สามารถเล่นชิ้นงานได้โดยไม่ต้องขอความช่วยเหลือจากเจ้าหน้าที่ผู้ดูแลชิ้นงาน I can play with the VR exhibit without any help from the staff.					

3. คุณรู้สึกเวียนหัวหรือไม่หลังจากที่เล่นชิ้นงาน VR แล้ว
Do you feel dizzy after play with the VR exhibit?

☐ ไม่เวียนหัว No ☐ เวียนหัว Yes

ส่วนที่ 3 ข้อแนะนำเพิ่มเติม

Part 3: other recommendations

1. สิ่งที่ประทับใจในชิ้นงานที่ใช้เทคโนโลยี VR

What are you impressive in the exhibit that using VR technology?

----

2. ขอแนะนำเพิ่มเติมในการการปรับปรุงชิ้นงานที่ใช้เทคโนโลยี VR

Do you have other recommendation?

---ขอขอบคุณที่สละเวลาในการร่วมวิจัยและตอบคำถามค่ะ----

Thank you for your participation.

Appendix F Study Five questionnaire

The proposed framework evaluation.

แบบสอบถามความพึงพอใจการใช้ Framework ในการออกแบบชิ้นงาน VR

The proposed framework evaluation questionnaire

ก่อนเข้าร่วมอบรมเชิงปฏิบัติการ (Pre-workshop)

ส่วนที่ 1: ข้อมูลพื้นฐาน
Part 1: User background experience

1. อายุ Age ________years

2. เพศ Gender: ☐ ชาย male ☐ หญิง female ☐ ไม่ประสงค์จะระบุ prefer not to say
☐ ต้องการอธิบายตัวเองว่า prefer to self-describe as____________________

3. ความเชี่ยวชาญ Expertise: ☐ นักออกแบบชิ้นงานนิทรรศการ Exhibit designer ☐ นักวิชาการ Science educator
☐ นักพัฒนาซอฟท์แวร์ Software developer ☐ อื่น ๆ Other..............................

4. ประสบการณ์การทำงานกับพิพิธภัณฑ์ How many years have you been working with STEM museums? ____________years

5. หน้าที่ความรับผิดชอบ What are your role and responsibility?

____

____

____

____

6. ในการพัฒนาชิ้นงานนิทรรศการใหม่คุณรับผิดชอบในส่วนไหนของกระบวนการพัฒนาชิ้นงาน What is your role and responsibility in the process of developing a new exhibit?

____

____

____

____

7. จงอธิบายกระบวน ขั้นตอนในการพัฒนาชิ้นงานนิทรรศการใหม่ จากประสบการณ์ในการทำงานของคุณ Please explain the process of developing a new exhibit from your experience.

____

____

____

____

____

____

____

____

____

____

8. คุณมีวิธีในการเลือกเทคโนโลยีต่าง ๆ มาพัฒนาเป็นชิ้นงานใหม่อย่างไร อะไรคือเงื่อนไขในการเลือกเทคโนโลยี How do you choose technology for creating a new exhibit? What are the criteria for you to make a decision?

____

____

____

____

____

9. เทคโนโลยี VR ตามความเข้าใจของคุณคืออะไร What is VR technology?

____

____

____

10. เทคโนโลยี AR ตามความเข้าใจของคุณ คือ อะไร What is AR technology?

____

____

____

11. คุณเล่น VR บ่อยแค่ไหน How often do you play VR?

☐ หนึ่งครั้งต่อวัน At least once a day
☐ สามครั้งต่อสัปดาห์ At least three times per week
☐ หนึ่งครั้งต่อสัปดาห์ At least once a week
☐ อย่างน้อยหนึ่งครั้งทุก ๆ 15 วัน At least once every 15 days
☐ แถบจะไม่ได้เล่น Rarely
☐ ไม่เคยเล่น Never

หลังเข้าร่วมอบรมเชิงปฏิบัติการ Post-workshop

ส่วนที่ 2 ความพึงพอใจการใช้งาน framework ในการออกแบบชิ้นงาน VR
Part 2: User Satisfaction Feedback

1. ชิ้นงานที่ได้ออกแบบใหม่ในวันนี้ คือ What's a new VR exhibit that you have designed today?

____

____

____

2. ประเมินให้ระดับความพึงพอใจของคุณกับข้อคิดเห็นในแต่ละข้อโดยการ ✓

Rate your level of agreement with each statement by ✓

ประเด็นข้อคิดเห็น Statement	ไม่เห็นด้วยอย่างยิ่ง Strongly Disagree (1)	ไม่เห็นด้วย Disagree (2)	เห็นเป็นกลาง Neutral (3)	เห็นด้วย Agree (4)	เห็นด้วยอย่างยิ่ง Strongly Agree (5)
ภาพรวม Overall					
1. กรอบแนวทางการออกแบบชิ้นงาน มีประโยชน์ช่วยให้สามารถเลือกเทคโนโลยีที่จะนำมาพัฒนาชิ้นงานแบบปฏิสัมพันธ์ใหม่ได้ The framework helps to choose the immersive technology for creating a new interactive exhibit.					
2. กรอบแนวทางการออกแบบชิ้นงาน มีประโยชน์ช่วยในการออกแบบเนื้อหาของชิ้นงานใหม่ The framework helps to design content for the new interactive exhibit.					
3. กรอบแนวทางการออกแบบชิ้นงาน มีประโยชน์ช่วยในการออกแบบส่วนของปฏิสัมพันธ์การโต้ตอบของชิ้นงานใหม่ The framework helps to design interaction action for the new interactive exhibit.					
4. กรอบแนวทางการออกแบบชิ้นงาน มีประโยชน์ช่วยในการออกแบบปฏิสัมพันธ์ทางสังคมระหว่างผู้เข้าชมในการออกแบบชิ้นงานใหม่ The framework helps to design social interaction for the new interactive exhibit.					
5. กรอบแนวทางการออกแบบชิ้นงาน มีประโยชน์ช่วยในการออกแบบระบบของชิ้นงาน The framework helps to design the system for the new interactive exhibit.					
6. กรอบแนวทางการออกแบบชิ้นงาน มีประโยชน์ช่วยในการออกแบบการจัดการความปลอดภัยและสุขภาพของผู้เข้าชมในการใช้ชิ้นงานของชิ้นงานใหม่ The framework helps to manage exhibit when setup in the real exhibitions					
7. เกณฑ์การเลือกระหว่าง VR กับ เทคโนโลยีอื่นของ กรอบแนวทางการออกแบบชิ้นงาน มีความเหมาะสมในการกำหนดเกณฑ์ต่าง ๆ The criteria for choosing VR vs. alternative technology of framework appropriate.					

ประเด็นข้อคิดเห็น Statement	ไม่เห็นด้วยอย่างยิ่ง Strongly Disagree (1)	ไม่เห็นด้วย Disagree (2)	เห็นเป็นกลาง Neutral (3)	เห็นด้วย Agree (4)	เห็นด้วยอย่างยิ่ง Strongly Agree (5)
8. องค์ประกอบโดยรวมของ กรอบแนวทางการออกแบบชิ้นงานใหม่ มีความเหมาะสม ต่อการนำ ไปออกแบบเป็นชิ้นงานจริง The components of framework for designing a new interactive exhibit appropriate.					
9. ข้อมูลรายละเอียดประกอบของ กรอบแนวทางการออกแบบชิ้นงานใหม่ ช่วยในการตัดสินใจในการออกแบบแต่ละองค์ประกอบของชิ้นงาน The support information along the framework helps you decide to design each component.					
แยกตามส่วนประกอบในกรอบแนวทางการออกแบบ Each component of the Framework					
10. การออกแบบเนื้อหา Content Design					
10.1 ส่วนประกอบของ การออกแบบเนื้อหามีความเหมาะสม ช่วยคุณในการออกแบบเนื้อหาของชิ้นงาน VR ใหม่ The element of Content Design is appropriate to help you to design content for a new VR exhibit.					
10.2 ข้อมูลรายละเอียดประกอบ ในการออกแบบเนื้อหาช่วยคุณในการตัดสินใจที่จะออกแบบเนื้อหาของชิ้นงานใหม่ The support information of the Content Design component helps you to decide to design content for a new VR exhibit.					
10.3 ข้อแนะนำและความคิดเห็นอื่นเกี่ยวกับส่วนประกอบของ การออกแบบเนื้อหา Do you have any suggestions and comments for the Content Design component?					
11. การออกแบบการกระทำ (ปฏิสัมพันธ์การโต้ตอบของชิ้นงาน) Action Design					
11.1 ส่วนประกอบของ การออกแบบการกระทำ ปฏิสัมพันธ์โต้ตอบ มีความเหมาะสม ช่วยคุณในการออกแบบการกระทำของชิ้นงาน VR ใหม่ The element of Action Design is appropriate to help you to design interaction for a new VR exhibit.					
11.2 ข้อมูลรายละเอียดประกอบ ในการออกแบบการกระทำ ปฏิสัมพันธ์โต้ตอบ ช่วยคุณในการตัดสินใจที่จะออกแบบการกระทำของชิ้นงานใหม่ The support information of the Action Design component helps you to decide to design interaction for a new VR exhibit.					
11.3 ข้อแนะนำและความคิดเห็นอื่นเกี่ยวกับส่วนประกอบของ การออกแบบการกระทำ ปฏิสัมพันธ์ของชิ้นงาน Do you have any suggestions and comments for the Action Design component?					

ประเด็นข้อคิดเห็น Statement	ไม่เห็นด้วยอย่างยิ่ง Strongly Disagree (1)	ไม่เห็นด้วย Disagree (2)	เห็นเป็นกลาง Neutral (3)	เห็นด้วย Agree (4)	เห็นด้วยอย่างยิ่ง Strongly Agree (5)
12. การออกแบบปฏิสัมพันธ์ทางสังคม Social Design					
12.1 ส่วนประกอบของ การออกแบบปฏิสัมพันธ์ทางสังคม มีความเหมาะสม ช่วยคุณในการออกแบบปฏิสัมพันธ์ทางสังคมของชิ้นงาน VR ใหม่ The element of Social Design is appropriate to help you design social interaction between visitors for a new VR exhibit.					
12.2 ข้อมูลรายละเอียดประกอบ ในการออกแบบปฏิสัมพันธ์ทางสังคม ช่วยคุณในการตัดสินใจที่จะออกแบบปฏิสัมพันธ์ทางสังคมของชิ้นงานใหม่ The support information of the Social Interaction Design component helps you to decide to design social interaction between visitors for a new VR exhibit.					
12.3 ข้อแนะนำและความคิดเห็นอื่นเกี่ยวกับส่วนประกอบของ การออกแบบปฏิสัมพันธ์ทางสังคมระหว่างผู้เล่น Do you have any suggestions and comments for the Social Interaction design component?					
13. การออกแบบระบบของชิ้นงาน System Design					
13.1 ส่วนประกอบของ การออกแบบระบบ มีความเหมาะสม ช่วยคุณในการออกแบบระบบของชิ้นงาน VR ใหม่ The element of the System Design is appropriate to help you design a system for a new VR exhibit.					
13.2 ข้อมูลรายละเอียดประกอบ ในการออกแบบระบบ ช่วยคุณในการตัดสินใจที่จะออกแบบปฏิสัมพันธ์ทางสังคมของชิ้นงานใหม่ The support information of the System Design component helps you decide to design the system for a new VR exhibit.					
13.3 ข้อแนะนำและความคิดเห็นอื่นเกี่ยวกับส่วนประกอบของ การออกแบบระบบชิ้นงาน Do you have any suggestions and comments for the System Design component?					
14. การออกด้านความปลอดภัยและสุขภาพของผู้ใช้งานชิ้นงาน Safety and Health					
14.1 ส่วนประกอบของ การออกแบบความปลอดภัยและสุขภาพของผู้เล่นชิ้นงาน มีความเหมาะสม ช่วยคุณออกแบบความปลอดภัยและสุขภาพของผู้เล่นชิ้นงาน ของชิ้นงาน VR ใหม่ The element of *Safety and health* component element is appropriate to help you design the safety and health concern factor for a new VR exhibit.					

ประเด็นข้อคิดเห็น Statement	ไม่เห็นด้วยอย่างยิ่ง Strongly Disagree (1)	ไม่เห็นด้วย Disagree (2)	เห็นเป็นกลาง Neutral (3)	เห็นด้วย Agree (4)	เห็นด้วยอย่างยิ่ง Strongly Agree (5)
14.2 ข้อมูลรายละเอียดประกอบ ในการออกแบบความปลอดภัยและสุขภาพของผู้เล่นชิ้นงาน ช่วยคุณในการตัดสินใจที่จะออกแบบความปลอดภัยและสุขภาพของผู้เล่นของชิ้นงานใหม่ The support information of the System Design component helps you to decide to design the safety and health concern factors for a new VR exhibit.					
14.3 ข้อแนะนำและความคิดเห็นอื่นเกี่ยวกับส่วนประกอบของ การออกความปลอดภัยและสุขภาพของผู้เล่น Do you have any suggestions and comments for the Safety and health component?					

ส่วนที่ 3 ข้อแนะนำเพิ่มเติม

Part 3: other recommendations

1. สิ่งที่ประทับใจในชิ้นงานที่ใช้เทคโนโลยี VR ? What are you impressed with within the exhibit that uses VR technology?

____

2. สิ่งที่คุณไม่ชอบ หรือต้องการปรับปรุง ชิ้นงานที่ใช้เทคโนโลยี VR? What do you dislike in the exhibit that uses VR technology?

____

3. ขอแนะนำ ความคิดเห็น เพิ่มเติมเกี่ยวกับกรอบแนวทางการออกแบบชิ้นงานที่นำเสนอ (framework) ในการออกแบบชิ้นงาน VR ใหม่
Do you have other recommendations about the framework?

____

---ขอขอบคุณที่สละเวลาในการร่วมวิจัยและตอบคำถามค่ะ----

Thank you for your participation

Appendix I The worksheet of the proposed framework for onsite workshop

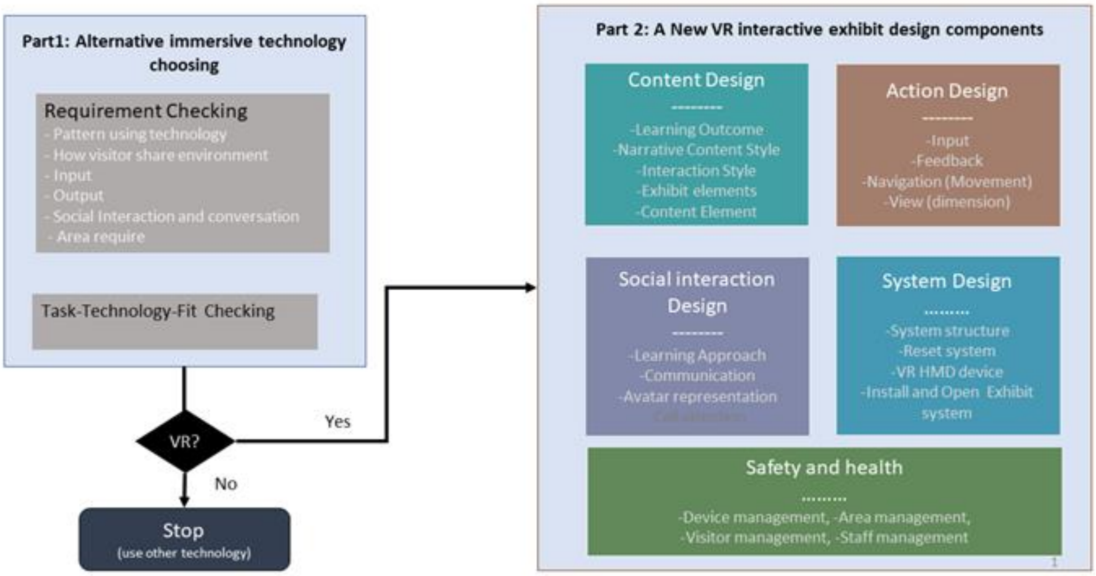
The worksheet of the proposed framework for onsite workshop

Proposed Framework
for design a new VR exhibit

V5 (18/April/2022)

0

Overview



1

Features Check list

Pattern using technology

- ❒ Online (virtual museum)
- ❒ Online (e-exhibit)
- ❒ Onsite continuous
- ❒ Onsite discrete
- ❒ Other thing ……………………………

Share experience in the same environment

- ❒ Asynchronous
- ❒ Synchronous

Social interaction and conversation

- ❒ Watch or listen only
- ❒ Less conversation
- ❒ Produce conversation between visitor

Area require (do you have area to setup ?)

- ❒ No area require
- ❒ Small area
- ❒ Big area

Input

- ❒ Passive (telling story and visitor just listen)
- ❒ Interactive (visitor can interact with the exhibit)
  - ❒ Using controller
  - ❒ Using free hand
  - ❒ Voice command
  - ❒ Other thing ……………………………………………

Output

- ❒ Visual and sound
- ❒ Additional sense
  - ❒ Vibration on controller
  - ❒ Tactile (feedback on object texture, touch sense)
  - ❒ Smell
  - ❒ Other thing ……………………………………………

2

TTF Check (task and technology compatible)

What is the action that you intend visitor do or interact with the exhibit?

……
……
……
……
……
……

How to implement, what is the technique that you will use to coding the game?

……
……
……
……
……
……

Does the technique have an efficiency that visitors can interact with the exhibit precisely when using your technique?

- ❒ Yes
- ❒ No

3

Content Design

Learning outcome

What you intend visitors do with the exhibit?

....
....
....
....
....
....

What you intend visitors feel with the exhibit?

....
....
....
....
....
....
....

What is knowledge or content that visitors get from exhibit?

....
....
....
....
....
....

What is skill that visitors will develop after play exhibit?

....
....
....
....
....
....
....

4

Content Design

Narrative content style

❐ Passive ❐ Interactive

Interaction style

❐ Exploration ❐ Discovery

❐ Role play ❐ Expression (such as can decorate avatar)
❐ Simulation (simulate situation such as drive tank submarine)

❐ Create and build ❐ Completion
❐ Challenge ❐ Collaboration

❐ Demonstrate a principle

❐ Fantasy ❐ Relaxation
❐ Sensation ❐ Sympathy
❐ Fellowship

5

Content Design (cont.)

Exhibit element

Topic content..

Narrative story..

6

Content Design (cont.)

Exhibit element (cont.)

- ❐ Role..
- ❐ Time constrains..
- ❐ Reward..

7

Action Design

Input (list of suggestion for VR)

❒ Controller action

❒ laser point and click to select object

❒ laser point drag and drop

❒ other..

❒ Body action

❒ move hand ❒ move head

❒ Gaze interact

Navigation

❒ Self walking, visitor walk around exhibit

❒ Using controller, visitor stand at one point

❒ use both hand controller

❒ use left hand controller

❒ use right hand controller

View

❒ 3D view ❒ 2D view

Feedback

❒ Sound ....

....

....

❒ Visual

❒ text ....

....

....

❒ image ....

....

....

❒animation..

....

....

❒ Controller vibration ....

....

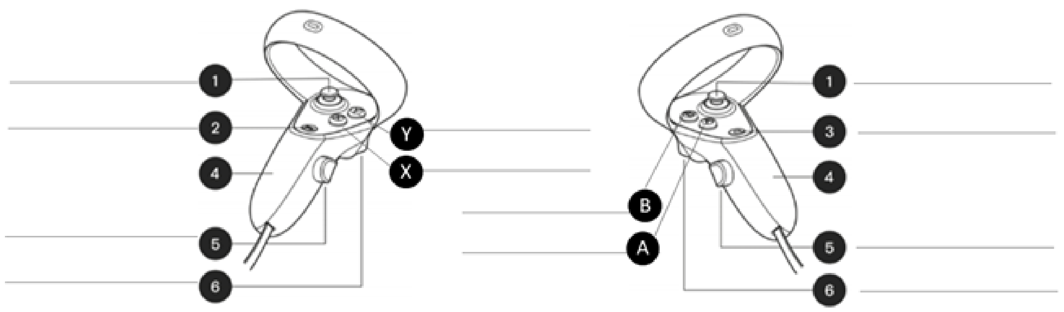
....

8

Action Design

Controller mapping (specify function)

Left hand controller **Right hand controller**



1. Thumbsticks
2. Menu button
3. Oculus button
4. Battery covers
5. Grip buttons
6. Triggers

9

Social Interaction Design

Learning Approach

- ❒ Constructivism (single player)

  ....

  ....

- ❒ Sociocultural
  - ❒ Co-presence

    ....

    ....
  - ❒ Co-player

    ....

    ....
  - ❒ Competition

    ....

    ....

Communication (tell the limitation)

- ❒ Conversation

  voice setup
  - ❒ same volume all distance
  - ❒ according to distance between player

    distance...

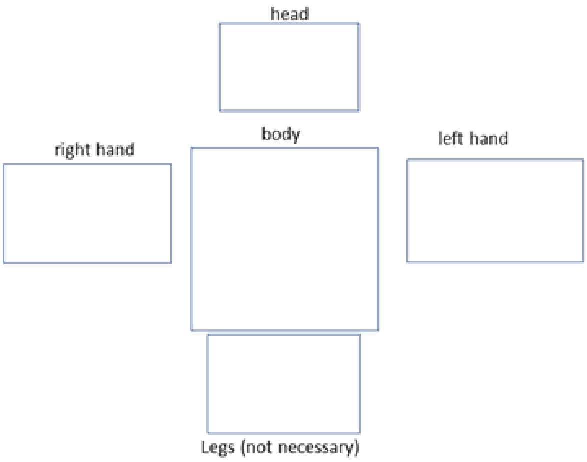
    minimum volume ....
- ❒ Pointing object

  ray pointer
  - normal colour..
  - hit interactable object colour.....................

Call attention

Social Interaction Design

Avatar representation (draw)



Where the position of ray beam out?

- ❒ hand
  - ❒ left ❒ right
- ❒ body
- ❒ head

System Design

System structure (draw flow chart)

❒ linear ❒ Depended on condition

Install and open exhibit system

How to install exhibit?

How to open the exhibit?

How to close the exhibit?

12

System Design (cont.)

Reset system

How to reset the system back to the start/home page?

When will the system restart?

VR HMD device (list of device)

Device type

❒ wire

Name of the Headset--

❒ wireless

Name of the Headset--

Tracking System

13

Safety and health

Device management

Where is the place to put the VR HMD?

How to provide the power for VR HMD and controller?

How to clean the VR HMD (face covering mask) for the next visitor ?

Area management

Where is the area for play the VR?

How is big?

14

Safety and health (cont.)

Visitor management

How to manage visitor have an experience with the VR exhibit?

■ Normal situation

■ Crowded situation

- How to manage queue

- How long in the maximum that allow a visitor play the VR exhibit?

Staff management

Do the exhibit need staff to support during visitor play with the exhibit?

❒ Yes How many staff ? ________people

❒ No

What are tasks that intend floor staff to support?

15

Appendix J The online form of the proposed framework for online workshop

The online form of the proposed framework for online workshop

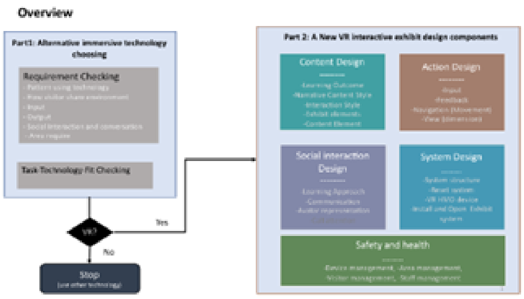
Proposed Framework For Design a new VR exhibit

Guideline for designing a new VR exhibit for STEM museums By Pornphan Phichai, a PhD student copyright © 2022 University of Glasgow Contact Email: p.phichai.1@research.gla.ac.uk

1 Framework overview | 2 Part1: Alternative immersive technology choosing | 3 Part 2: A New VR interactive exhibit design components | 4 Content Design | 5 Action Design | 6 Social Interaction Design | 7 System Design | 8 Safety and health | 9 Submit

Group Name:

Overview



Add content...

Save   Next

1/9

Proposed Framework For Design a new VR exhibit

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1 Framework overview — 2 Part1: Alternative immersive technology choosing — 3 Part 2: A New VR interactive exhibit design components — 4 Content Design — 5 Action Design — 6 Social Interaction Design — 7 System Design — 8 Safety and health — 9 Submit

Part1: Alternative immersive technology choosing

Features Check list

Pattern using technology

- ☐ Online (virtual museum)
- ☐ Online (e-exhibit)
- ☐ Onsite continuous
- ☐ Onsite discrete
- ☐ Other

Please Descript if you choose "**Other**"

Share experience in the same environment

- ☐ Asynchronous
- ☐ Synchronous

Social interaction and conversation

- ☐ Watch or listen only
- ☐ Less conversation
- ☐ Produce conversation between visitor

Input

- ☐ Passive (telling story and visitor just listen)
- ☐ Interactive (visitor can interact with the exhibit)*

If you choose "**Interactive**", please specify the input method you intend to use.

- ☐ Using controller
- ☐ Using free hand
- ☐ Voice command
- ☐ Other thing**

**Please describe if you choose "Other thing"

Proposed Framework For Design a new VR exhibit

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1 Framework overview — 2 Part1: Alternative immersive technology choosing — 3 Part 2: A New VR interactive exhibit design components — 4 Content Design — 5 Action Design — 6 Social Interaction Design — 7 System Design — 8 Safety and health — 9 Submit

Part1: Alternative immersive technology choosing (cont.)

Output

- [ ] Visual and sound
- [ ] Additional sense*

* If you choose "Additional Sense", please specify the out method you intend to use.

- [ ] Vibration on controller
- [ ] Tactile (feedback on object texture, touch sense)
- [ ] Smell
- [ ] Other thing**

**Please describe if you choose "Other thing"

TTF Check (task and technology compatible)

What is the action that you intend visitor do or interact with the exhibit?

How to implement, what is the technique that you will use to coding the game?

Does the technique have an efficiency that visitors can interact with the exhibit precisely when using your technique?

- ( ) Yes
- ( ) No

*If the technique does not compatable with VR technology, you should change either action or technology.

Back | Save | Next

2/9

Proposed Framework For Design a new VR exhibit

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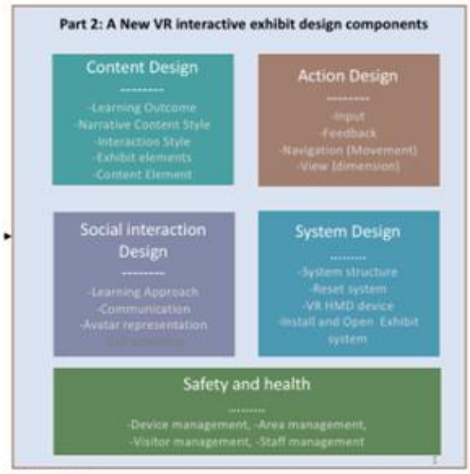
1 Framework overview · 2 Part1: Alternative immersive technology choosing · 3 Part 2: A New VR interactive exhibit design components · 4 Content Design · 5 Action Design · 6 Social Interaction Design · 7 System Design · 8 Safety and health · 9 Submit

Part 2: A New VR interactive exhibit design components



Add content...

* After you check that the feature of VR technology supports the new exhibit you intend to create, use Part 2 as a guideline to design the detail of each component of the new VR exhibit.

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Proposed Framework For Design a new VR exhibit

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Content Design

Learning outcome

What you intend visitors do with the exhibit?

What you intend visitors feel with the exhibit?

What is knowledge or content that visitors get from exhibit?

What is skill that visitors will develop after play exhibit?

Narrative content style

- ◯ Passive
- ◯ Interactive

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Content Design (cont.)

Interaction style

- ◯ Exploration
- ◯ Discovery
- ◯ Role play
- ◯ Expression (such as can decorate avatar)
- ◯ Simulation (simulate situation such as drive tank submarine)
- ◯ Create and build
- ◯ Completion
- ◯ Challenge
- ◯ Collaboration
- ◯ Demonstrate a principle
- ◯ Fantasy
- ◯ Relaxation
- ◯ Sensation
- ◯ Sympathy
- ◯ Fellowship
- ◯ Other

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Content Design (cont.)

Exhibit element

Topic content

Narrative story

Role

Time constrains

Reward

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Action Design

Input

- [ ] Controller action --> laser point and click to select object
- [ ] Controller action --> Laser point drag and drop
- [ ] Controller action --> Other**
- [ ] Body action --> Move Hand
- [ ] Body action --> Move head
- [ ] Gaze interact

** Please describe if you choose "Other" for the Controller action

Navigation

- [ ] Self walking, visitor walk around exhibit
- [ ] Using controller, visitor stand at one point**

If you choose "**using controller**" please specify how to use the controller?

- [ ] use both hand controller
- [ ] use left hand controller
- [ ] use right hand controller

View

- ○ 3D view
- ○ 2D view

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Action Design (cont.)

Feedback

☐ Sound

please describe what kind of sound feedback

☐ Visual --> Text

Please describe what kinds of text feedback

☐ Visual --> Image

Please describe what kind of the image feedback

☐ Visual --> animation

Please describe what kind of the animation feedback

☐ Controller vibration

Please describe what kind of the controller vibration

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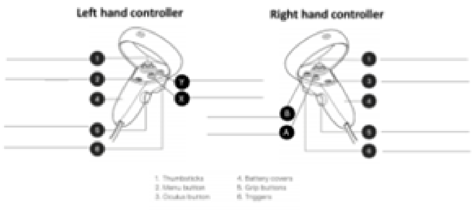
Action Design (cont.)

Controller mapping (please specify function)



Please describe which button do you want to use and their function.

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Social Interaction Design

Learning Approach

☐ Constructivism (single player)

please describe

☐ Sociocultural --> Co-presence

please describe

☐ Sociocultural --> Co-player

please describe

☐ Sociocultural --> Competition

please describe

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Social Interaction Design (cont.)

Communication

☐ Conversation

please define how to setup volumn in the virtual environment.

Voice setup

◯ same volume all distance

◯ according to distance between player

distance

minimum colour

☐ Pointing object

please define how to setup ***ray pointer.***

Normal colour

when hit interactable object colour

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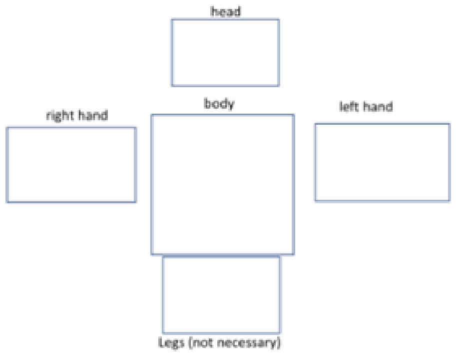
Social Interaction Design (cont.)

Avatar representation (please draw)



Please upload image of your drawing avatar representation

Choose File

Where the position of ray beam out?

- [ ] Hand --> left hand
- [ ] Hand --> right hand
- [ ] body
- [ ] head

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System Design

System structure (draw flow chart)

- ◯ Linear
- ◯ Depended on condition

❐ linear ❐ Depended on condition

Please draw the flow chat of the system and upload

Choose File

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System Design (cont.)

VR HMD device

Device type

- ◯ wire
- ◯ wireless

Name of the Headset

Tracking System

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Safety and health

Device management

Where is the place to put the VR HMD?

How to provide the power for VR HMD and controller?

How to clean the VR HMD (face covering mask) for the next visitor ?

Area management

Where is the area for play the VR?

How is big?

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Safety and health (cont.)

Visitor management

How to manage visitor have an experience with the VR exhibit?

Normal situation

Crowded situation --> How to manage queue?

Crowded situation --> How long in the maximum that allow a visitor play the VR exhibit?

Staff management

Do the exhibit need staff to support during visitor play with the exhibit?

- ◯ No
- ◯ Yes

If choose "yes" Please specify How many staff that the new VR exhibit needs?

What are tasks that intend floor staff to support?

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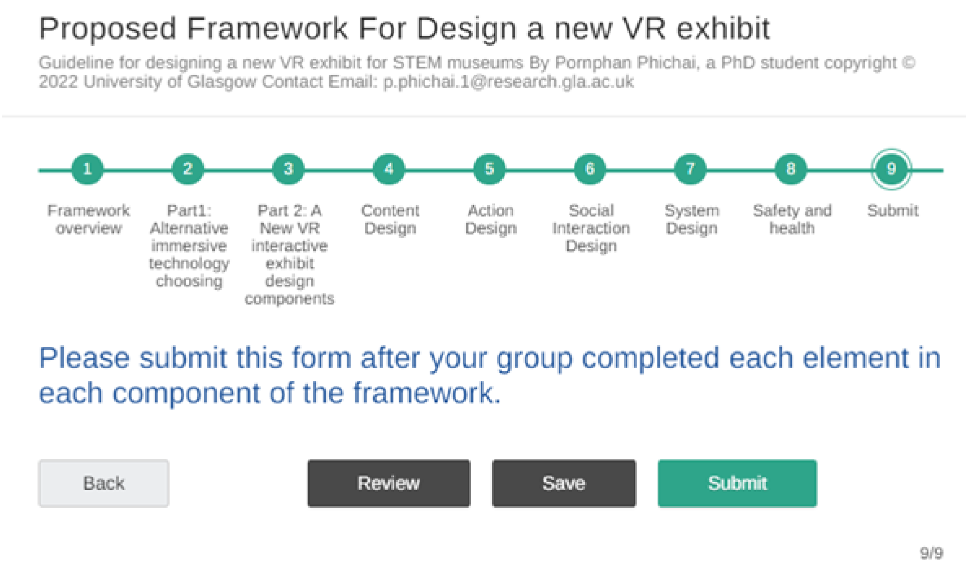

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Please submit this form after your group completed each element in each component of the framework.

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