VR in the Past:
Game-based Learning of
Archaeological Processes

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Abstract

Serious games as the application of gamification in education domain has become a hotspot over the last few years. However, its potential for engaging the public to learn archaeology hasn't been widely explored. On the other hand, the increasing popularity of VR technology creates more space and possibilities for serious game design.

In this paper, a serious game for archaeology called "Finding AVA" was designed and developed by applying WebVR technology. This game aimed to find out the learning effectiveness for serious games in archaeology education as well as the potential of VR in serious games. The overall evaluation result was positive and implied great development space for archaeology serious games.

Declaration

I declare that this dissertation was my individual work and composed by myself. The game developed in this project was original. The references were all marked clearly.

(Xiangjun Liu)

Acknowledgements

During this project, I received great help and support from many people.

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Chapter 1

Introduction

"Serious games" has become a prevalent word in many academic domains in recent years. It basically shares the same meaning with game-based learning which is about leveraging digital gaming technology to achieve learning outcomes (Corti, 2006). The potential benefits of serious games in education is widely accepted because of games' highly motivating feature (Annetta, 2008), and the process of designing games for non-game contexts is called gamification (Deterding et al, 2011). Although the advantages of serious games are undeniable, there is still a lack of empirical evidence proving its effectiveness especially in respect of knowledge transferability to the real world (Mortara et al., 2014). After all, it is difficult to bridge the gap between virtual world and physical world.

The advancement of virtual reality (VR) technology makes it possible to simulate the real world by providing users an immersive experience, hence narrowing the gap between the unreal and real (Coquillart, Brunnett and Welch, 2010). Therefore, VR has great potential in serious games and it is even more valuable for gamification of academic contexts that require historical accuracy and realism like archaeology. On the other side, the emergence of WebVR enhances the accessibility of VR technology and enables the application to be more lightweight.

The design of the game "Finding AVA" in this project is an attempt to apply gamification theory to archaeology academic field using Web VR technology. The overall result of evaluation shows a positive learning outcome, indicating the game is effective in teaching people archaeology knowledge. However, the VR experience was not very successful because of some limitations. This attempt also revealed some important elements contributing to learning effectiveness, game design and VR immersion.

This project is in collaboration with many partners including archaeologists from the Achavanich Beaker Burial Project which is the real background of the narrative in "Finding AVA", Samsung who generously offered GearVR device and technical guide, and National Museum of Scotland who will possibly provide the space for final implementation.

This paper contains six chapters in total. The next chapter will introduce the overall background including the concept of serious games and WebVR technology. Chapter 3 will explore gamification theory and discuss serious game design in facets of theory and method. The whole designing process including context analysis, conceptual design, and prototype development will be described in Chapter 4. The evaluation of the game “Finding AVA” will be shown in Chapter 5. In final Chapter 6, discussions about the current results as well as future work will be covered.

Chapter 2

Background

This chapter will introduce the concept of serious games and analyze the potential of the state-of-the-art gaming technology for addressing the challenges faced by serious games in archaeology education domain. The overall goal of this project will be further confirmed and clarified in the conclusion section.

2.1 Serious Games

2.1.1 Defining Serious Games

Ever since people began to realize the positive effects of playing games (Subrahmanyam and Greenfield, 1994), there has been a resurgent interest in considering games as a new educational tool. Consequently, the concept of game-based learning, which refers to designing games for educational purposes (Connolly et al., 2012), has been gradually highlighted and valued. With the continuous research and practice on this topic, in order to distinguish it from other traditional games for pure entertainment, there emerged a new term for this game genre: Serious Games.

The term soon became prevalent and widespread since 2002 when the video game "America's Army" was released and "The Serious Games Initiative" was founded (Susi, Johannesson and Backlund, 2007). In spite of this, there is no universally recognized definition of serious games so far. Literally speaking, the phrase even seems to be self-contradictory because "serious" and "games" are mutually exclusive words to some extents (Ritterfeld, Cody and Vorderer, 2009). How could games embrace seriousness?

According to Michael Zyda, the creator of America's Army, serious game is "a mental contest, played with a computer in accordance with specific rules, that uses entertainment to further government or corporate training, education, health, public policy, and strategic

communication objectives" (Zyda, 2005). He argued that although pedagogy which aims to impart knowledge and skills is a key feature of serious games, it should come after the entertainment component. However, the opinion of focusing on the fun elements in serious games was challenged by Michael and Chen. They proposed that "A serious game is a game in which education (in its various forms) is the primary goal, rather than entertainment" (Michael and Chen, 2005). In other words, learning purpose in serious games is superior to amusement. Without over emphasizing the relationships between education and entertainment, Annetta defined serious games as "electronic/computer-access games that are not designed for commercial purposes but rather for training users on a specific skill set" (Annetta, 2010).

Although the definitions of serious games have various concerns and perspectives, there is still a consensus around them: use of game elements or gaming technology and having a learning objective other than mere entertainment (Ulicsak, 2010).

2.1.2 Impacts of serious games

Serious games have the potential to facilitate learning and may serve as a new cultural tool to extend the effectiveness and influences (Morris et al., 2013). As a new mechanism for teaching and training, they are capable of supporting knowledge acquisition, affective satisfaction and behaviour change (Connolly et al., 2012).

Due to the highly motivating feature of games, serious games tend to engage learners more easily along with positive emotional reactions (Annetta, 2008). This active participation contributes to learning effects compared to passive acceptance in traditional educational scenarios (Garris, Ahlers and Driskell, 2002). Besides, serious games offer an opportunity to learn by doing and experience situations first-hand without the cost of real world consequences which could possibly encourage learners who do not do well in conventional environments (Annetta, 2008). Despite the mixed and limited empirical evidence in this field, there were still some research results supporting the argument (Connolly et al., 2012). For example, Gopher, Well and Bareket (1994) found that trainees in flight school with 10 hours' video game training outperformed those with standard training (Gopher, Well and Bareket, 1994). Beale, et al. (2007) compared the understanding level of

cancer knowledge for a game playing group with another non-playing group and concluded that video games could be an effective approach to health education (Beale et al., 2007).

Affective outcomes cover many aspects related to feelings and emotions including confidence, attitudes and self-efficacy (Wilson et al., 2009). It seems obvious to deduce the relationships between games and affection because the enjoyment brought by immersive experience could itself be viewed as a positive emotional effect (Connolly et al., 2012). Going more deeply, how the attributes of games influence the affective outcomes has been widely studied. It showed that "challenging", "fantasy" and "control", as critical components to motivation, could significantly affect the participant's attitudes to learning (Wilson et al., 2009). Thomas, Cahill and Santilli (1997) suggested that successful involvement of adventure computer games could improve self-efficacy and enhance confidence with respect to safe sex negotiations (Thomas, Cahill and Santilli, 1997).

Regarding behaviour change, it contains a broader conception and more implicit process. In spite of learning to be their primary objective, serious games could subtly influence people's behaviour both positively and negatively. Gentile and Gentile (2008) argued that violent video games incorporate many key features of successful learning, thus leading to players more likely to think and behave aggressively (Gentile and Gentile, 2008). Lavender (2008) evaluated the effectiveness of a persuasive videogame "Homeless: It's no game" and found that most people tend to be more sympathetic towards the homeless after playing the game (Lavender, 2008). Similarly, by analyzing the efficacy of a computer game "The Great Escape" for teaching children fire safety information, Morrongiello (2012) concluded that serious games could largely improve young children's awareness of dangerous situations and the corresponding reactions (Morrongiello et al., 2012).

2.2 Serious Games for Archaeology

In spite of above prominent impacts of serious games on learning, little consideration has been put on using games to support archaeology education (Anderson et al., 2010). There are some video games using archaeology elements as parts of their virtual environment (e.g. Civilization) or virtual simulations without good integration with game elements (e.g. Adventures in Fugawiland), but they cannot really be called serious games aiming to teach the public archaeology knowledge (Watrall, 2017). This is partly because archaeology is relatively conservative and professional and it requires historical accuracy and cautious

attitude. Without proper awareness and interdisciplinary collaboration, the game would easily be just a game with an extra layer of pedagogical content (Mortara et al., 2014) or a simple computer simulation without any fun or enjoyment. It is always difficult to achieve the balance between educational objectives and entertaining features within the serious game and this is even more the case for "serious" archaeology.

Another challenge for archaeological games is lacking formal empirical evidence to support the learning outcomes (Mortara et al., 2014) especially in terms of knowledge transferability to the real world. Fieldwork which requires innumerous practice plays a crucial and irreplaceable role in learning archaeology (Croucher, Cobb and Brennan, 2008). Although games could provide the learner a platform to obtain repeat training, the gap between virtual world and physical world is still difficult to be effectively narrowed.

2.3 The Potential of Virtual Reality

Since the emergence of Virtual Reality (VR) technology, it has been applied in many fields such as cinema presentation, medical training and video games. By combining with professional VR head-mounted displays (e.g. HTC Vive, Samsung Gear VR) and utilizing 3D image or model construction technology, the user would be immersed in a completely simulated digital environment (Anderson et al., 2010). An important aspect of VR technology is stimulating human senses - basically sight, hearing and touch - to give the user a feeling of experiencing the real world rather than a virtual one (Coquillart, Brunnett and Welch, 2010). This more realistic and immersive presence is the most outstanding advantage of VR application and, in the meantime, the greatest potential for development of serious games in archaeology (Virvou Katsionis and Manos, 2005).

Since archaeology education is demanding in historical reconstruction and accuracy, VR are much more preferable because it can simulate countless real-life scenario in an ecological way (Ritterfeld, Cody and Vorderer, 2009) and the realistic environment gives learners the possibility to interact with objects in a more meaningful and actual context (Mortara et al., 2014). The user could touch, move and control these virtual objects as in the physical world, which could be helpful for transferring knowledge to real operational environments. Therefore, with respect to current problems in serious games for archaeology mentioned in the previous section, we can argue application of VR could hopefully largely improve the situation.

Furthermore, 3D technology advancement, especially 3D scanning, makes it possible to move remote sites or precious items to your eyes. It can reconstruct and render the objects from real data without losing many details (Bruno et al., 2010), hence enabling the learning process even more engaging and informative. More importantly, the user could manipulate the valuable archaeological items without the risks of damage or contamination (Mortara et al., 2014).

Although VR games have great potential and development space in the domain of archaeology education, there still exists many limitations and difficulties. The creation of VR games is complex and it requires a wide spectrum of expertise (Bruno et al., 2010), from graphic elements and game mechanics design to advanced modelling and programming skills. Their development is normally based on a deep understanding of gaming engines such as Unity and Unreal (Appreal-vr.com, 2017). These engines integrate various renderers and processing units which could provide superior visualization and physics support, thus largely improving the programming progress and immersive effects (Anderson et al., 2010). They are super powerful, but also relatively difficult to be conquered. Besides, VR applications built on these engines cannot be easily and widely accessed (Anderson et al., 2010). The user needs to download and install the corresponding environment to run the game, which will inevitably set extra requirements to the hardware carrier and engender inconvenience.

2.4 WebVR and A-Frame

Thanks to development of internet technology and web visualization, it could nowadays offer the public ubiquitous access to VR experience through the World Wide Web (Anderson et al., 2010) and at the same time, the application itself is more lightweight and less complicated.

The concept of WebVR is proposed with the intent of providing the public with wider access to VR experience through a simple compatible browser (Webvr.info, 2017). Its development is normally based on WebGL (Web Graphics Library) which is a cross-browser API for rendering 3D graphics (Khronos.org, 2017) and three.js which is a javascript library for creating web 3D graphic animation and interaction (Threejs.org, 2017). Compared to game engines, WebVR is much more approachable since the digital generation is very familiar with browsers and network.

A-Frame, developed by Mozilla VR team, is a framework for building WebVR experiences (A-Frame, 2017). It aims to create a easy and powerful way to develop high-performed WebVR content. The framework is built upon HTML (Hypertext Markup Language) and completely compatible with DOM (Document Object Model), thereby quite friendly to web developers. You can create an engaging VR environment by just wrapping simple tags inside the “body” element and process them like normal HTML pages.

In addition to above, the highlight of A-Frame lies in the powerful entity-component-system (shown in Figure 1) which allows developers to declare, customize and reuse their own components (shown in Figure 2). This highly flexible and extensible feature makes the program structure clearer and more robust.

These advantages of A-Frame present a strategy to overcome the complexity and accessibility problems of VR technology, therefore we could possibly achieve great effects on engaging the public to learn archaeology by applying it.

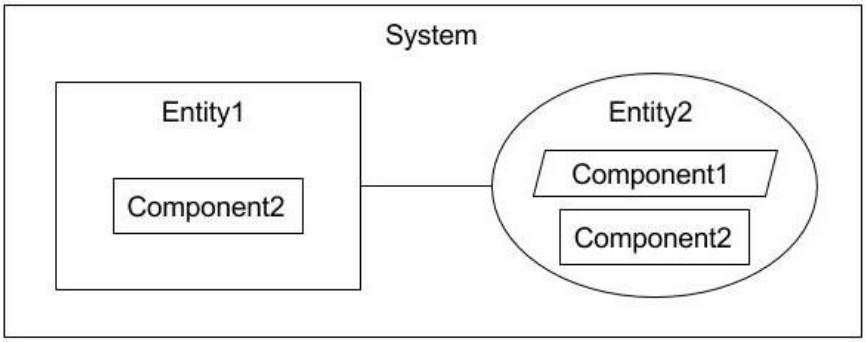


Figure 1 The entity-component-system structure of A-Frame

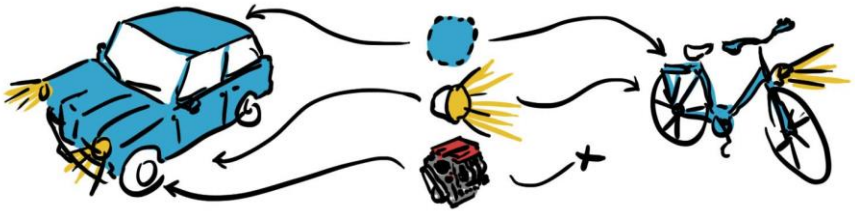


Figure 2 Understanding the components in A-Frame
(Image by Ruben Mueller from vrjump.de)

2.5 Conclusion

Serious games have drawn much attention nowadays, resulting in a great impact in many fields, especially education. Although there is still a lack of enough experimental evidence attesting the learning effects of serious games, their potential as a new training tool cannot be overlooked. With the help of state-of-the-art game technology like VR, more immersive and realistic learning environment could be created to facilitate the learning process and knowledge transferability. This is even more meaningful and valuable for subjects like archaeology, which require some extents of historical reduction and accuracy. Moreover, WebVR (e.g. A-Frame) significantly improves the current situation of virtual reality, namely complex development and difficult access. Therefore, we can argue that WebVR technology provides an effective method to extend public archaeology and in the meantime, may lead to better learning outcomes. This paper attempts to use A-Frame to design and develop a VR game installed in the museum for public archaeology education and evaluate its effectiveness and usability as well.

Chapter 3

Game Design Theory

This chapter will explore gamification theory, serious games design and VR games design. They are the basis for designing the game in this project and also the guideline for the whole process.

3.1 Gamification and Game Elements

According to Deterding et al. (2011), Gamification is “the use of game design elements in non-game contexts” (Deterding et al, 2011). These non-game contexts include education, business, health, etc. Therefore, serious games are the application of gamification in education domain and they are created through gamification of traditional learning content (Kapp, 2012).

The purpose of gamification is to motivate action by providing an engaging game-playing experience. Although there are countless games and various game genres in the market, the majority of them share some significant characteristics which we call game elements (Deterding et al, 2011). It is the combination and interplay of these elements that make a game appealing and motivating, then what are these important game elements? Based on a review of former literature, Garris (2002) summarized these features into six dimensions: fantasy, rules/goals, sensory stimuli, challenge, mystery and control (Garris, Ahlers and Driskell, 2002). On the other side, Kapp (2012) listed these elements including goals, rules, competition or cooperation, time, reward structure, feedback, levels, storytelling, curve of interest, aesthetics and replay (Kapp, 2012). By understanding and comparing these two categorizations, I conclude the game elements as followed:

- Goals

A clear goal is the prominent difference between game and play. Friends running casually in the playground is play, but a game immediately starts when someone says “Shall

we compete to see who is fastest running to the end?" (Kapp, 2012) Salen and Zimmerman said that "Goals are fundamental to games...at the outcome of a game, the goals are either reached or not reached and this quantifiable outcome is part of our definition of games." (Salen and Zimmerman, 2004) Goals arouse the players' desire to prevail and motivate them to pursue success. In order to make the goal apparent, specific and well instructed, it is better to divide it into some small sustained objectives and an ultimate goal. In this way, the player could achieve accumulated accomplishment and acquire continuous excitement.

- Rules

Rules are another important part constituting games and without rules, games cannot be properly played and managed. There are multiple layers of rules within a game and their collaboration contributes to good functionality and performance. Operational rules or system rules define the basic principles which players must follow in this virtual world. For example, pressing right direction key enables moving forward. Procedural rules are those guiding the game process like you can only open the door by finding the hidden key. Imported rules means facts existing in the real world including common sense (e.g. Dice has six sides), etiquette (e.g. no lying) and instructional rules which embody the real learning process (e.g. Doctors cannot do surgery before finishing the examination). The imported rules may be challenged in some fiction games which are full of imaginary and not limited to people's world, but they are valuable for games based on the physical world like serious games.

- Feedback

Real-time feedback is an outstanding edge in games and it provides information to guide users. There are mainly two forms of feedback in a game. The first one is informing players of the current situation. For example, how much time is left and how many scores have been got. This helps people to make decisions and adopt strategies. The other one is giving different responses depending on the player's action, thus implying the rightness or wrongness. You may hear a sharp sound or receive an error message to remind you of the incorrect operation. This is extremely meaningful to people's learning process because people learn through failure and the feedback can guide the right direction (Kapp, 2012).

- Environment

The environment element refers to those factors benefiting the construction of the whole background. They are essential to create an engaging experience. Sensory stimuli (e.g. aesthetic graphs, sound effects or vivid animation) helps to build more immersive surroundings. Storytelling or narrative is the storyline where the user could find his or her identity, thus giving them a sense of mission to accomplish the goal.

- Motivation

This motivation category involves all the other remaining elements because they are related to the same subject: how to motivate people to play and learn? Most gamification researchers study users' motivations based on self-determination theory (SDT) which posits that people can be intrinsically or extrinsically stimulated (Tondello, 2016). Extrinsic motivation comes from external sources like a reward or a demand for obligation. Intrinsic motivation origins from people's psychological needs. In other words, people are willing to do the thing just because the task meets some mental demands. Deci and Ryan (2000) explained the psychological needs more detailedly and classified them into three types: competence, autonomy and relatedness (Deci and Ryan, 2010).

All the game elements belonging to this category are either intrinsic or extrinsic motivation factors. By setting different levels or challenges neither too difficult nor too simple, the player can feel capable of completing the sub-tasks. This is the embodiment of competence need. The control elements which means some extents of authority or ability to select different contexts or paths to solve the problem reflects autonomy. Finally, playing with other people (e.g. competition and cooperation) makes the user feel related to each other. These are all internal motivations, whereas reward structure and time constraints are obviously extrinsic motivations.

Although fantasy and mystery (curiosity) are not directly related to any psychological needs mentioned above, they are essential to the attractiveness of the game. The fantasy or mystery world is full of imaginary and unknowns which could easily evoke people's curiosity and exploration, therefore Malone and Lepper (1987) defined them as characteristics for building an intrinsically motivating learning environment (Malone and Lepper, 1987).

Among the five categories, the first four elements (i.e. goals, rules, feedback and environment) are indispensable in gamification, but not all the motivation elements are necessary. The situation varies depending on many factors such as gamification domain and objectives (Kapp, 2012). This also indicates that selection and application of the motivation elements are crucial because it is the main discrepancy between different games. Therefore, only by careful analysis, targeted use and clever combination could we make the most use of them.

3.2 Serious Games Design

3.2.1 Design Theory

Serious games are games and hence share many common characteristics mentioned above. However, due to the primary educational objectives, there still exists some preferences or special considerations in their design (Michael and Chen, 2005).

- Biggest is not necessarily the best

When designing serious games, in order to enhance the learning breadth, it is natural to think about covering as much knowledge as possible. However, the biggest does not necessarily mean the best. Enormous contents tend to make the system complex and confuse the player as well. The key points are easy to be submerged and ignored, thus weakening the learning effect instead. Besides, being limited to time, budget, computer hardware and software, developing a large game is basically unfeasible in many cases. Serious game designers must learn to make a selection within constraints and focus on the most important part needed to be taught (Michael and Chen, 2005).

- Essential game elements

Annetta (2010) summed up a nested model containing six components to describe the most important facets of serious game design. The left part of Figure 3 illustrates the framework beginning with identity, followed by immersion, interactivity, increased complexity, informed teaching and ending with instructional (Annetta, 2010).

On the other hand, Rieber (1996) (Rieber, 1996) pointed out fantasy which is part of immersion elements can be exogenous and endogenous. The former means creating an imagined context completely insulated from the real learning situations, while the latter are tied closer to the real environment. Comparing the two types of fantasy, Rieber noted that the endogenous fantasy is more motivating in serious game design.

Based on the aforementioned game elements, nested model and fantasy theory, I rebuilt a elements model (shown in the right part of Figure 3) by matching corresponding game elements to the related component and it acts as the basic guideline for the subsequent elements design for this project.

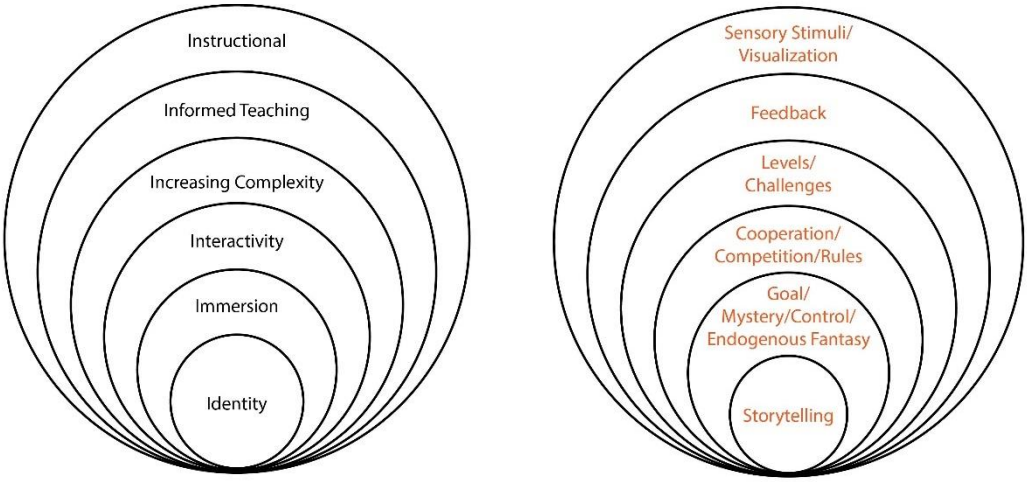


Figure 3 Game elements for serious games design

3.2.2 Design Method

There are two dominant methods for gamification design, namely “Scrum” and “ADDIE” (Kapp, 2012). The “Scrum” model is an agile development approach based on iterations and usually used in complex project, whereas “ADDIE” involves a linear process with five main steps which are “Analyze”, “Design”, “Develop”, “Implement” and “Evaluate” (Gustafson and Branch, 2002). Since this short-term project is not every complicated and in a clear

context, I followed the “ADDIE” model to implement my design. Figure 4 represents one way to describe the relationship among the five stages in “ADDIE” method.

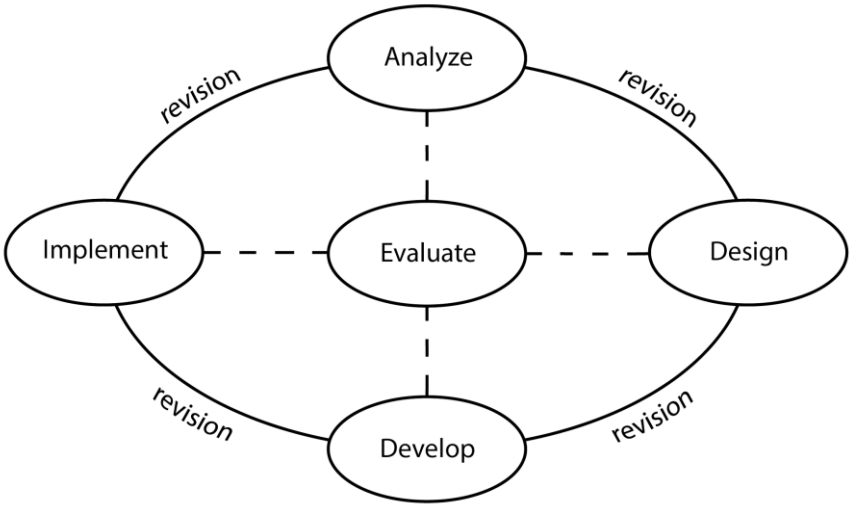


Figure 4 The “ADDIE” design model

The first step “Analyze” often includes understanding the problems and identifying the learning content. The results directly influence the next “Design” step in which the game mechanics are decided and the storyboards are produced. After that, we can go to the programming part and turn it into a real game in the “Develop” stage. “Implement” usually means trying out the system in the environment for which it was designed. “Evaluation” is conducted by two means: formative evaluation which happens throughout the whole process and summative evaluation which is implemented at the end. The formative evaluation may result in several times of revision during the whole period.

3.3 VR Games Design

The immersive experience is the outstanding edge for VR technology and it is also the main reason for VR’s great potential in serious games. The immersion stems from all-dimensional realistic sensory including visual, tactile and auditory. Since haptic technology hasn’t been fully used in VR domain so far, and sound design is a rather independent topic, I mainly focused on visual design in this project.

Visual perception is the most intuitive channel for people to feel the world and so is the virtual world. Therefore, the primary condition for immersive VR game is a realistic visual stimulus. This can be achieved by seamless scene design and natural interaction design.

I called it “seamless” to mean conformance to human vision. In other words, virtual contents should be in a proper size or distance to allow users to correctly understand them and it should change correspondently based on the user’s movement (WhatIs.com, 2017). Besides, 3D scene modeling is crucial including material, texture and light rendering. The virtual models should contain enough details like shadows and wrinkles to mimic the physical world better.

Another important factor is natural interaction design. People communicate with the world through continuous interaction. The game environment should simulate the interaction naturally as in the real world. For example, turning a handle to open a door should imitate the movement that enables users to feel that they are really holding something.

Chapter 4

Design Process

The design procedure basically followed the “ADDIE” design method introduced in the previous section. This chapter will describe the first four steps during the game design (i.e. analyze, design, develop and implement) and will also present different versions of prototype as well as their formative evaluation.

4.1 Context Analysis

4.1.1 Archaeology Consideration

Archaeology is a sophisticated academic area and includes countless professional research and practice methods like stratigraphy, chronology and topological sequences (Renfrew and Bahn, 2011). It is impossible and unfeasible for one game to cover all the elements and we should also keep in mind that “Biggest is not necessarily the best”. Therefore, the crucial first step is to identify the learning emphasis.

For years, the public image of archaeology is limited to digging or excavation (Rubio-Campillo et al., 2017). People tend to think of archaeology as treasure hunting. However, the excavation is only a small tip of the iceberg and the real purpose of archaeology is enhancing the understanding of humankind by revealing the past. The archaeology workflow typically begins with discovery, followed by identification and ends up with research. More specifically, archaeologists first excavate and collect history artifacts, then complete the cleaning, repairing, cataloguing and dating, finally analyze and interpret the findings. This integral procedure should be manifested in the game to change the public’s one-sided view towards archaeology.

During the whole archaeological process, the learning and training contents are not limited to the professional knowledge and research methods, but also scientific thinking

(Rubio-Campillo et al., 2017). Scientific thinking encompasses a set of skills including evidence investigating, problem-solving and logic reasoning (Morris et al., 2013). These key points are seldom considered and covered in archaeology educational games, but they are the core of contemporary archaeology (Rubio-Campillo et al., 2017). Therefore, scientific thinking is another aspect that should be conveyed to the public.

With respect to game design, there are also some special concerns for archaeology education. The public fascination with archaeology lies in a sense of curiosity evoked by its mystery (Rubio-Campillo et al., 2017). People tend to be fond of exploration and discovery, which happens to be an important component in archaeology practice. Therefore, it is particularly suitable to employ some adventurous elements like puzzles in the game (Mortara et al., 2014). Besides, it is not difficult to implant archaeology insights into puzzles since they were intended to test a person's ingenuity and knowledge, so the educational relevance of the puzzles is obvious and clear (Connolly et al., 2012).

4.1.2 Museum and VR Considerations

The special environment of museum leads to some extra considerations when designing the game. Visitors of museum are normally from diverse backgrounds, so the game must avoid using some cultural symbols which may confuse users or cause misunderstandings. Additionally, due to the time and space restrictions, it is inappropriate to set the game too long or too difficult, as this will increase the waiting time and reduce the influence scope (Mortara et al., 2014). This is also the case when applying VR. Longtime of wearing VR headset will possibly cause nausea and discomfort (Gamedesigning.org, 2017). Since most people are not familiar with this new technology, it is more user-friendly to make the game easier to understand and operate.

4.2 Conceptual Design

4.2.1 Game Mechanics

Based on the above context analysis, a simple puzzle adventure game could be a reasonable choice to impart archaeology knowledge to the public. Even further, I found the Room Escape game which is a subgenre of the adventure games fits the context quite well.

The typical scenario for the room escape game is that you need to search objects, parse clues and solve puzzles to get out of the locked room within a limited time (Nicholson, 2015). Compared to traditional adventure games with large scenes, room escape games are usually short and limited to a small space to explore but in the meantime, without losing any main elements from other adventure games (En.wikipedia.org, 2017). They are still puzzle-driven and filled with mystery, but they are not complex both in rules and operation. Because of these characteristics, room escape games are rather approachable to the public audience.

In addition to above, room escape games could also well encompass scientific thinking as well as the three main stages for the archaeological process. Searching hidden clues and using them correctly require strong investigating skills, whereas integrating various information and making smart decisions need problem-solving and inference skills. These are all important parts of scientific thinking and they can be perfectly embodied in the design of room escape games. Besides, the three stages (i.e. discovery, identification and research) could easily be set as three locked rooms or levels with their corresponding themes and learning objectives. Hence, the learner will naturally experience the three steps like they were in a real archaeology practice. In this respect, there actually has been some researches which were conducted to prove the feasibility and learning outcomes of room escaping. The Engineering School at Universitat Autònoma de Barcelona incorporated a Room Escape activity in teaching Computer networks and Information Security. The puzzles in the game were designed directly related to the subjects and the result turned out to be extremely positive. Students were highly motivated and claimed that this interesting method was very helpful to knowledge acquisition, especially for understanding complicated concepts (Borrego et al., 2017).

By combining room escape game and essential serious game elements summarized in the last chapter, some components can be designed and confirmed. Firstly, and most importantly, it is the storytelling. Only by putting the characters in a specific storyline could they become alive and vivid. Considering the endogenous fantasy, I rewrote the story in a background of the real Achavanich Beaker Burial Project and changed it to have a sense of

mystery and adventure (shown in Table 1). The terminal goal for the game is to find the person including some facts about buried thousands of years ago, and because of this, I named the game “Finding AVA”. It will be divided into three levels or challenges based on the three main stages throughout the archaeology process. The sub-goals for the levels are digging the site in the wild, classifying the unearthed artifacts in the lab and conducting researches to reveal the past in the research room, respectively. The completion of these goals is supported by solving puzzles which merge archaeology knowledge. There are basically no cooperation elements within the game, but it could be developed to be a competition to see who clears all the levels in the least amount of time. Other game elements like feedback, sensory stimuli and visualization will be discussed in the subsequent interface and interaction design part since they are more relevant. These elements which have been confirmed are summed up in the following table (see in Table 1):

Game Elements	Description
Name	Finding AVA
Genre	Adventure / Room Escape
Story	In 1987, an archaeology expedition team found a burial site in north Scotland, but unfortunately, the site was collapsed because of a heavy rain. All the members safely escaped but the tools, records and findings were all buried. You, as a young archaeologist will be brought back to the excavation site to continue and complete the task.
Goal	Find the person buried in the site and explore some facts about him or her.
Levels	3 Levels: Discover - dig the site (in the wild) Identify - sort out and classify the artifacts (in the lab) Research - find the answers about the person and the past (in the research room)
Rules	Move and click / Solving puzzles to clear levels
Playing Mode	Single-player with timing system

Table 1 Defining the game "Finding AVA"

4.2.2 Puzzle Design

The core of the game is the puzzles because they are the bridge to convey knowledge and the main stimulus that motivates players to continue the adventure. A good puzzle cannot be designed too challenging or too simple since the former will frustrate the player and the latter may bring not enough sense of achievements (Tulleken, 2017).

In order to learn the basic gameplay structure of room escape game and design the puzzles, I spent hours playing the popular puzzle game "The Room" which won the Best British Game award in 2013 (The cover of the game is shown in Figure 5) (Awards.bafta.org, 2017). I even experienced the physical Room Escape (see Figure 5) to feel the difference between the digital environment and real tactile surroundings. Through comparison and summary, I found that due to the full body interaction, the physical Room Escape is more attractive and immersive, but they share many commons in respect of puzzles design.

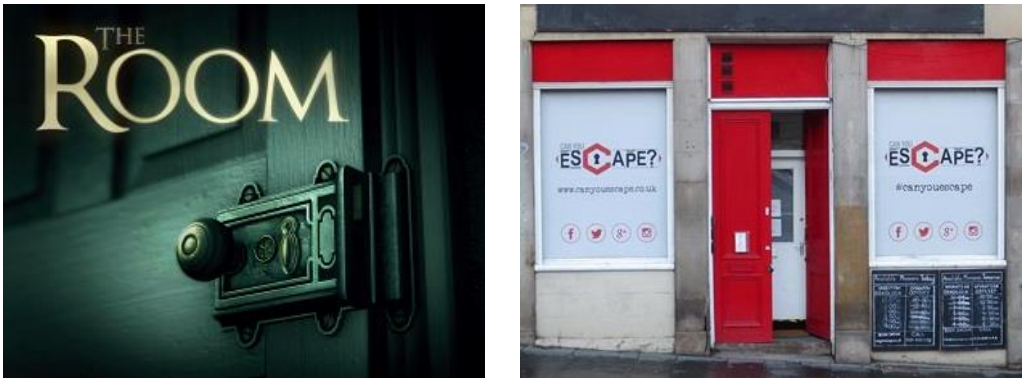


Figure 5 The video game "The Room" and the real Room Escape

- Clues are everywhere

Hidden clues exist in every corner, you must keep your eyes open and stay the questioning attitude to every object around you. This means in spite of the constrained space in room escape game, I still need to make full use of it. For VR experience, someone may feel not comfortable or easily get tired if the game keeps them looking around, but this is also another exceptional advantage for VR technology to simulate the real world.

- Lock - the indispensable element

It seems that if there are no lock elements in the game, it cannot be called a room escape game. Behind the lock, it normally hides some tools or other important clues without which you will be unable to complete the follow-up tasks. A key or a password is required to open the lock, so the first step is to figure out what the password is according to other clues around you. Generally speaking, the password can be found by referring to information related to numbers, patterns, etc. There exist some kinds of correspondence between them.

- Construct and compose

This is another prevalent puzzle type which is similar to jigsaws. The player needs to find the scattered pieces and put them together to rebuild a complete shape or object. Once correctly constructed, it will then trigger other puzzles or uncover some clues. In this way, the storyline moves forward. Although there is no real lock hanging there, it is actually functioned as another type of lock. For example, in one chapter of the game "The Room", there is a table lacking two badges, if the player fills the gap, the table will open and present a telescope for investigating other clues.

- Combine and synthesize

Sometimes, the hints are interrelated rather than independent. They must be combined together to find the solution, just like solving a mathematics question. Condition A cannot conclude the answer, but with the help of condition B, then the scope would be narrowed down to the correct answer. Therefore, this puzzle type requires your associative ability as well as memory capacity.

Based on these common rules and learning emphasis, I designed three main puzzles with one at each level in my game and they are directly related to archaeology knowledge:

1) The alphabet lock for the first "Discover" level

The alphabet lock aims to get people know about the function and using order of various digging tools. There is a paper with tools' icon and name on it. Besides, a number is written at the corner of each icon. Thus, the password is composed of all the first letters of the tool names and they are in the order indicated by the numbers. The paper hint and the lock is shown in Figure 6 and the password is "CRPLMT". Except for implying the password, the

numbers also mean the using order of the tools. Next, the player must follow the order to use tools one by one to dig the site.

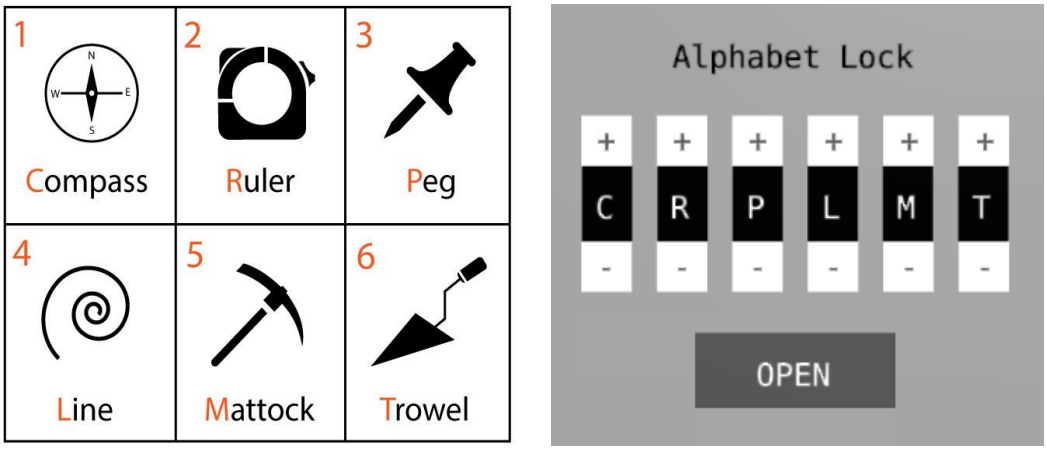


Figure 6 The password hint and the lock

2) Reconstruct the beaker and the body for the second “Identify” level

The player must identify each fragment of the beaker and reassemble them into a complete one (shown in Figure 7), whereas for the skeleton remains, the user should recognize that each bone belongs to which part of the body and put them in the right position of the body frame (shown in Figure 7). Once finished, the table under the beaker and bones will be split up and other objects will appear. By doing this, the player is supposed to understand what should be done after excavating the historic relics.

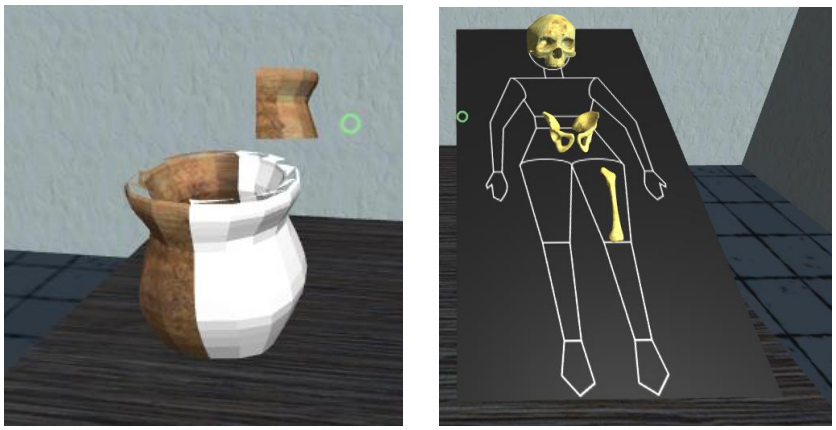


Figure 7 Reconstruct the beaker and the body

3) Complete the question board for the final “Research” level

The question board contains four questions in total. They are: what is the gender? how old is he or she? what is the height? and are there any plants in his or her living environment? The basic idea is using information about the bones and the beaker to deduce the answers. The human bone research methods will be provided, so what the player needs to do is applying the knowledge immediately by integrating the information (shown in Figure 8).

Figure 8 The question board and the bone information

4.2.3 The Storyboard

After designing main puzzles, the gameplay workflow could be defined as followed (see in Figure 9). The complete and detailed storyboard in a format of graphs with texts explanation is shown in Appendix A. It is theoretically better to arrange more branches rather than only one main storyline, which could give users more control over the game, but considering the short time as well as the room escape game genre, there is generally only one entrance and exit and the solution to each puzzle is unique. However, the exploring processes in the middle may vary like in the second level marked by the red line (the player could either reconstruct the beaker first or identity the human bones first). This difference can also give the player some extents of freedom to enjoy the game.

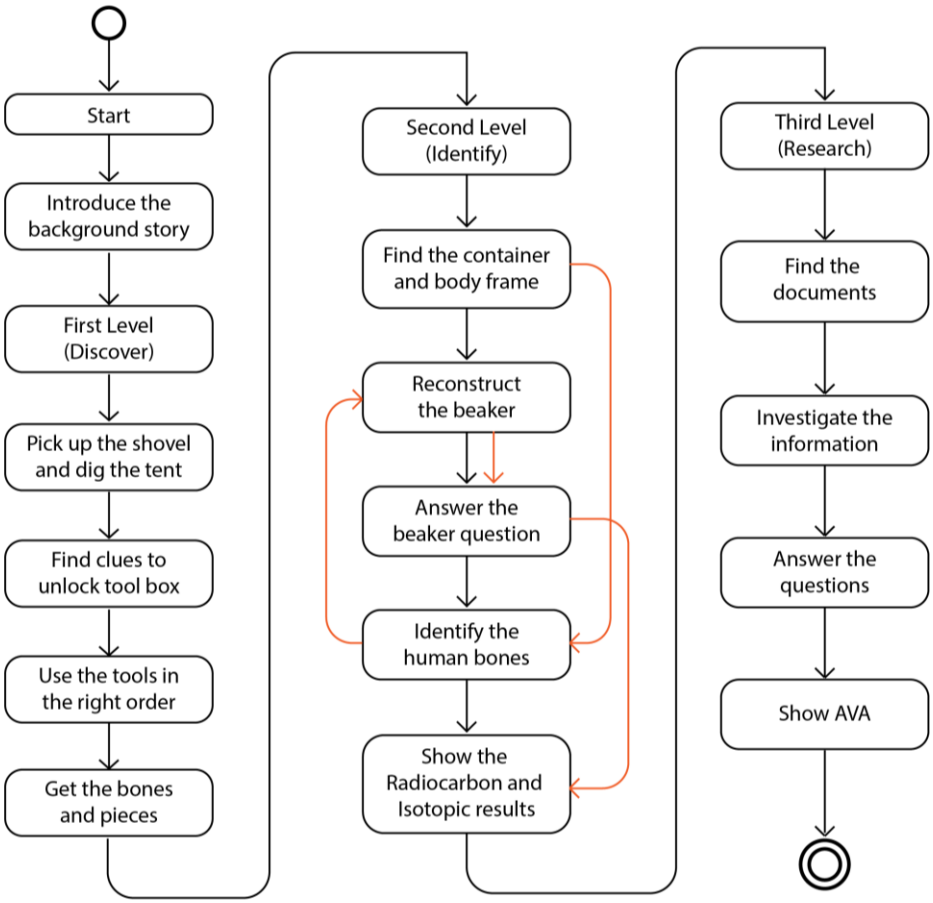


Figure 9 The gameplay workflow

4.3 Prototype Development

4.3.1 Game Modules Design

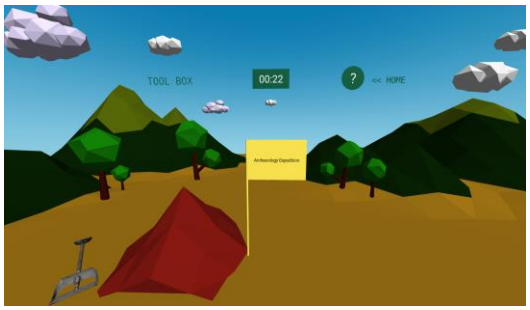
1) Interface Design

The interface determines the public's first impression of the game and is the main source for sensory stimuli. Beautiful interface could pleasure the player’s mind and thus enable the learning process more enjoyable. This is also another motivation to promote learning outcomes. In order to guide the users to complete the tasks better, the interface was designed to be simple and clean in a consistent style. For example, I drew a series of icons using

Adobe Illustrator to represent tools, bones and pieces (shown in Figure 10, some were modified based on icons downloaded from online (Iconfont.cn, 2017)).

Figure 10 Icons for tools, bones and pieces

Besides, I chose colors neither too dark nor too bright to make players feel visually comfortable. Since the color display is related to the screen resolution, I would test it using google cardboard and iPhone 6 every time before settling down to make sure it is well presented with VR device. Another noteworthy point is the camera position which determines the distance and angle of the first person's perspective. I must setup the camera in a proper location which could simplify the player's operation and create a view close to real life. Other objects were also adjusted proportionally to cater for the entire scene. This is particularly important for creating an immersive experience as mentioned in the previous game design section. Finally, the main interfaces for welcome page and three levels are presented in Figure 11.



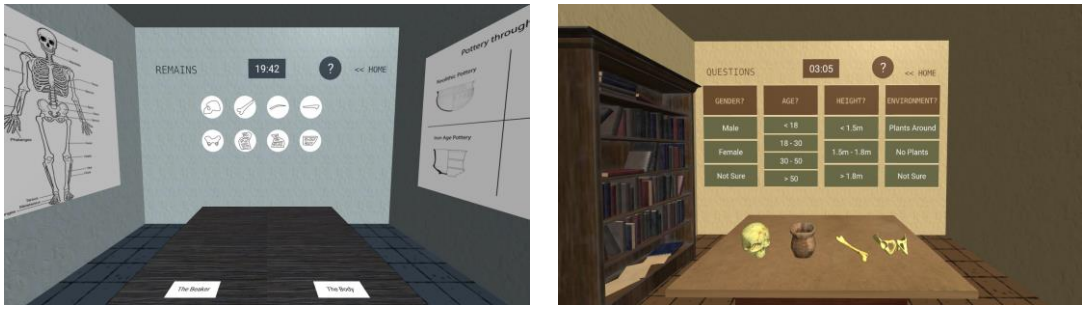


Figure 11 Main interfaces of the game

In terms of space utilization in the 3D dimension, I basically used the space around the player except for the back. The player can complete all the operations by moving up and down, left and right without no need to turn around. In this way, the user could enjoy the realism as well as not being too cumbersome. For example, in the first level, the password and map hint will be pinned to the left and right, the player uses tools to dig the site which is just beside his or her feet (shown in Figure 12).

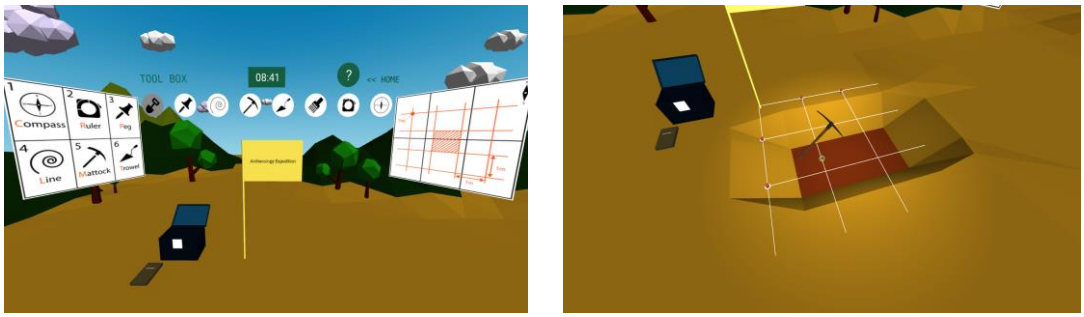


Figure 12 The 3D space utilization

Except for aesthetics consideration, data visualization is an important and effective method for instructional design (Annetta, 2010). Making good use of it could more clearly and efficiently convey the knowledge because people love vivid graphs far more than plain texts. Therefore, I tried to avoid using large paragraph of texts, except for the more detailed archaeology knowledge summary at the end of each level. For example, in the final "Research" level, the player needs to find the documents containing the research methods to solve the puzzles. The content is textually long and thus easily make players lose patience,

so I visualized it with graphs and simple descriptions (shown in Figure 13), hence allowing players to get the key points at a glance.

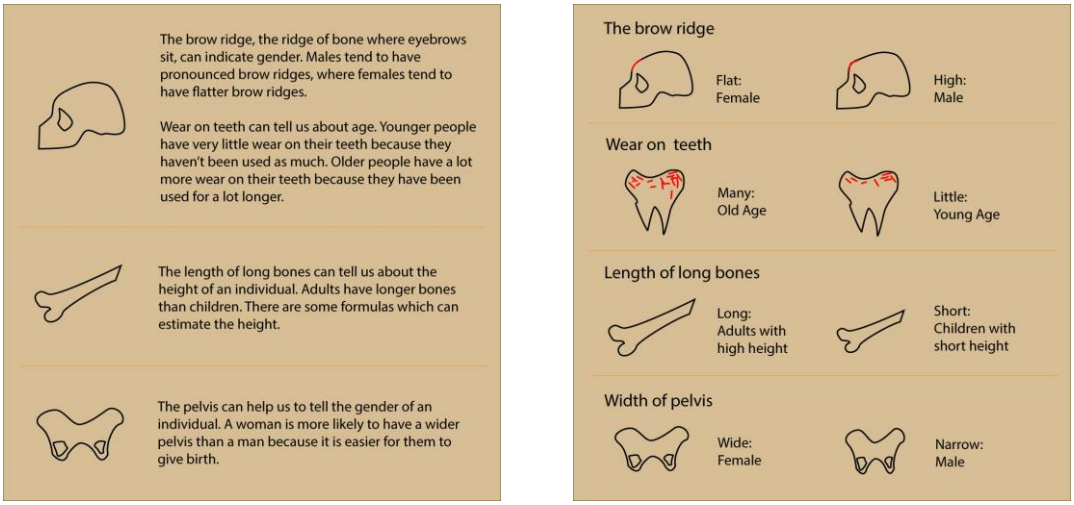


Figure 13 Visualization of texts

2) Interaction Design

Interaction design largely depends on the input/output (I/O) structure (Crawford, 1984). For this project, the input device is the Samsung GearVR headset. It supports three degrees of freedom (3DoF) with only rotational tracking which means you can only look around but not walk around (A-Frame, 2017). There is a focus cursor functioning as eyes and it will move with the movement of the headset. Except for hovering, clicking to trigger some action is allowed too. For output part, the platform is a Samsung smartphone with Samsung Internet browser, so it could be visual elements like graphs or animation, and sound effects like music or echoism. In fact, the I/O structure is similar to mouse and computer screen. The only difference is that mouse is operated by hands but VR headset is controlled by the head. Hence, the interaction between the player and the game is basically realized by moving, focusing and clicking. In order to imply those clickable objects, I added some visual changes when hovering the cursor on them. For example, an orange outline will be shown when the player move the cursor on the icons; the excavation site will glow when holding a digging tool in hand; the book containing important information will turn red when looking at it (shown in Figure 14).

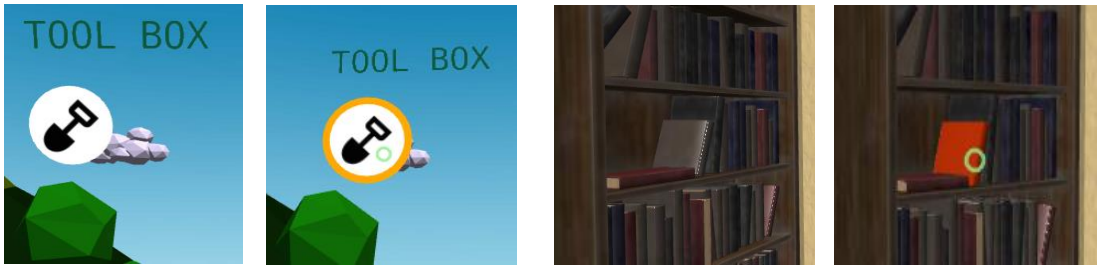


Figure 14 Interaction hints for clickable objects

Besides, in order to mimic the physical interaction in the real world more naturally, the selected tools or bones will move together with the cursor just like the user is really holding the tool or bone (shown in Figure 15). It could work better with hand controllers or more advanced headsets that have position tracking function. This device will allow users to really walk around and move their hands, thus making the whole experience more realistic.

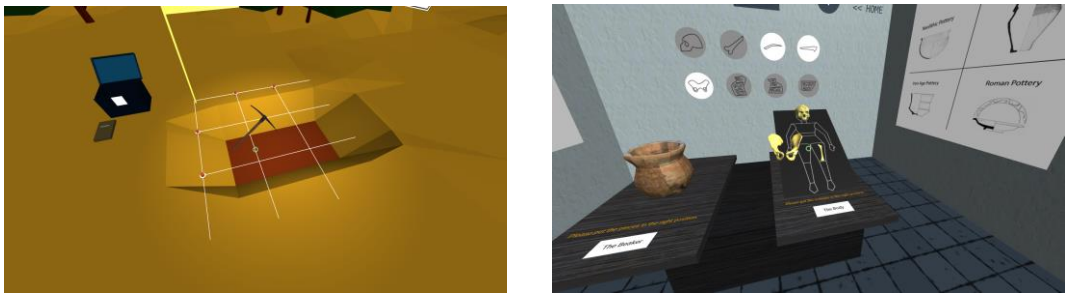


Figure 15 Hand movement simulation

Another essential function for interaction is giving users immediate feedback to effectively guide them. This is particularly important for serious games. People learn knowledge by continuous "trial and error" in the game, so the player needs to know whether he or she did correctly or where the mistake is. In this game, if the learner used the wrong tool to dig the site, an error message "Wrong tool! Mind the using order" will pop out to remind the user. It will disappear automatically after two seconds to avoid hampering other operations. Besides, after using the tool or the remains, the corresponding icon will turn dimmed to indicate that the tool has already been used (shown in Figure 16).

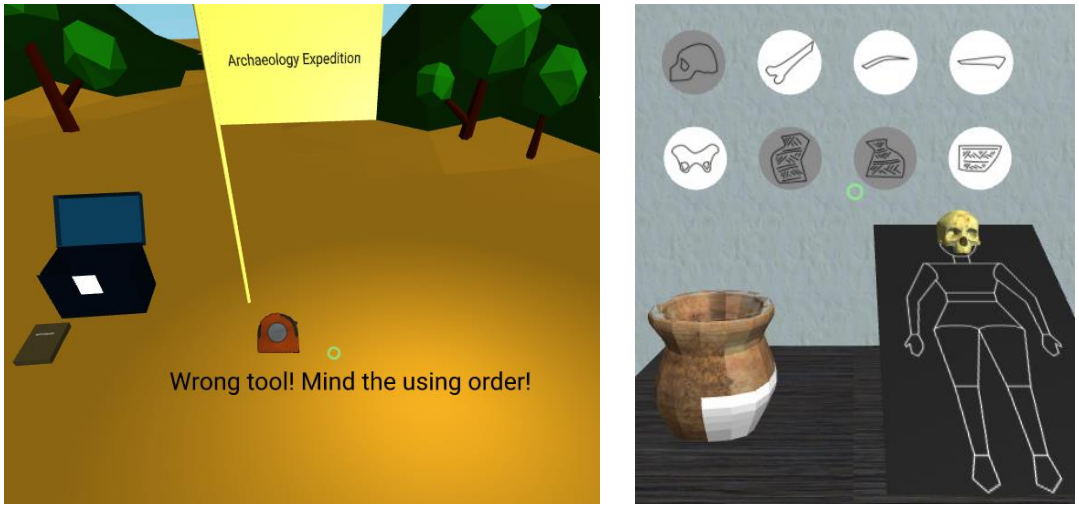


Figure 16 Immediate feedback

3) 3D Model Design

A-Frame, as a webVR framework, is executed and demonstrated through browsers. Therefore, the performance of the browser largely determines the final presenting effect and also sets some limitations to some facets including model design (Scianna, Guardia and Scaduto, 2016). Generally speaking, developers will control the size of content shown on web in case that the browser gets stuck or crashes. From the following Figure 17, we can see that every model will take time to load. The bigger the model is, the more slowly the browser will run. Hence, in order to smooth the performance, I should minimize the size of 3D models as they are the main contributor to not fluent browsing.

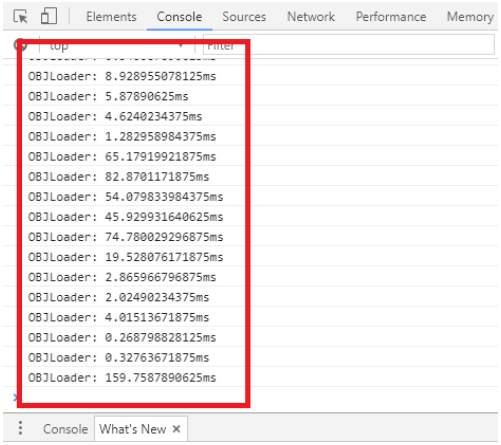


Figure 17 Loading time for every 3D model

Considering the archaeological authenticity and historical accuracy, it is better to use original models in the game. The archaeology team only provided me with the real skull and beaker models, so I tried to get those of other bones and remains by 3D scanning. Unfortunately, because of lacking experience in 3D scanning and model post-processing, I haven't got time to study the related knowledge carefully and finally failed to complete the mesh registration with MeshLab to reconstruct the models. On the other side, it is also unfeasible to incorporate all 3D scanned models because the size of it is normally huge for web and could be up to hundreds of MB each. Although real models could help build a more realistic environment, we put more emphasis on using game mechanics to motivate learning and cultivate the learner's scientific thinking, rather than archaeological models' reconstruction which itself could be another big topic. Therefore, I decided to build my own models using Blender.

I chose the models to be in a low poly style, which means using a relatively small number of simple polygons to construct the model. The biggest advantage for low poly is creating small size models which require a little amount of time rendering and loading (Josh O'Caoimh, 2017), thus it is perfect for web games. Fox example, the size of the landscape model with the dimension of 40m x 40m in the first level (shown in Figure 18) is only 159 KB.

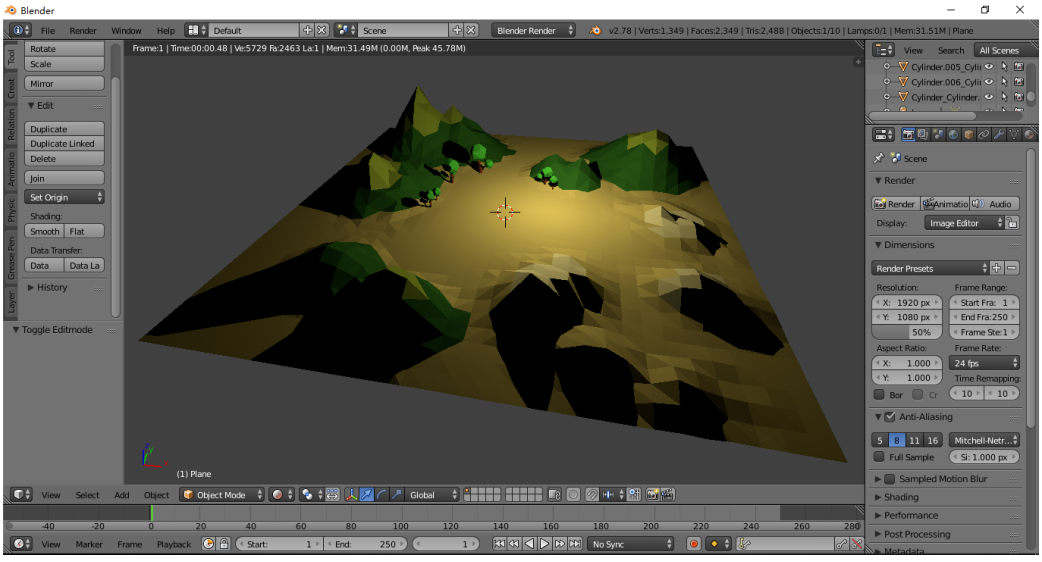


Figure 18 Landscape model in low poly style

Moreover, in order to make models more realistic, instead of adding a simple material, I attached the texture from real bones and beaker to the surface of the corresponding models using UV editor (shown in Figure 19). The texture files are in JPG format and they were all tailored with Photoshop to be in a resolution of power of two (e.g. 512px x 512px, 1024px x 1024px) in order to eliminate the resizing time and to be correctly rendered in WebGL (Scianna, Guardia and Scaduto, 2016).

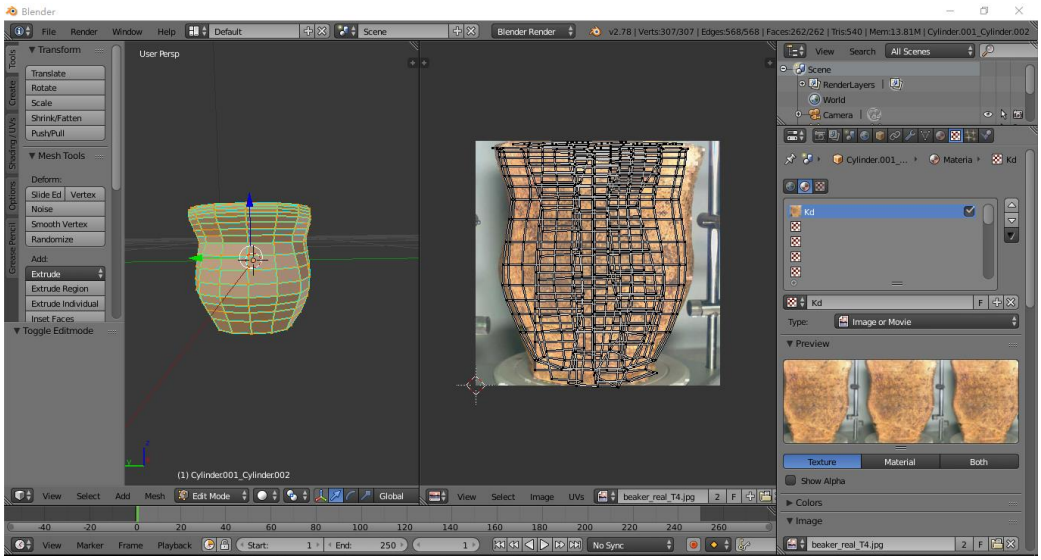


Figure 19 Attaching real textures to models

4.3.2 Program Structure

I mainly used HTML 5, JavaScript and A-Frame 0.5.0 to prototype the game. The HTML file builds the content framework, A-Frame elements nested in HTML tags construct main objects while the JavaScript file contains components and functions to control behaviours. The program was tested in some popular browsers including Google Chrome 60, Microsoft Edge 40, Mozilla Firefox 54, and Safari 10. The whole program structure is displayed in Figure 20. Different colors represent the three languages respectively.

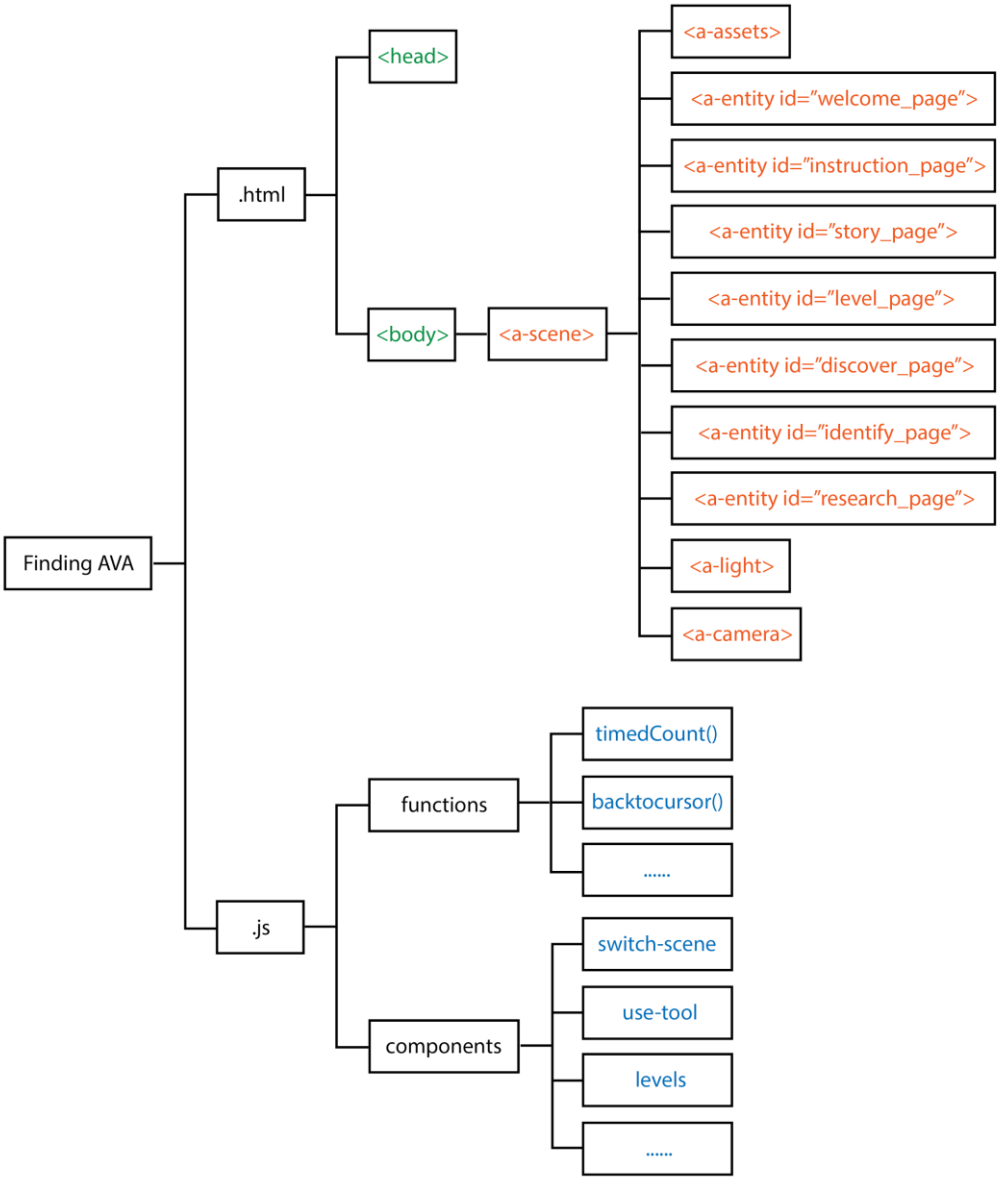


Figure 20 Program structure

I will mainly talk about three important components:

1) switch-scene

This component is to realize the switch between different scenes by controlling the visibility of the corresponding entities. From the figure above, all the objects in the same page are wrapped in an entity with a unique id, so what I need to do in this component is to set the previous page invisible and at the same time, set the next page visible. In the HTML

file, calling the component is adding an attribute like this: switch-scene="from:#level_page; to:#discover_page".

2) levels

Every time the user enters the level page, it will check which level the player is in and the appearance and interaction will change depending on the result. The default level is 1 (discover), level 2 (identify) and level 3 (research) are locked under this circumstance. The levels will be unlocked one by one. For example, only if the player finished the discover level will the identify level be unlocked. I programmed this “level” component to monitor the “checklevel” event that was emitted each time the player entered the level page (this part can be seen in “switch-scene” component code above) and modify the interface accordingly.

3) use-tool

This use-tool component aims to check that whether the player uses the tools in correct order. If correct, the tool will work normally, otherwise, the error message will pop out. In order to realize it, I declared two variables “currenttool” and “previoustool” to store the tool currently in hand and the previously used tool. Each time a tool is successfully used, the variable “previoustool” will be incremented by one. By comparing the values of these two variables, we know whether the order is correct.

4.3.3 Prototype Iteration

The game experienced three versions of prototype. In the first prototype, I focused more on implementing functionalities, so the interface was rough, archaeology instructions were not complete and models were temporarily replaced by simple spheres or boxes (as shown in Figure 21). Prototype V1.0 was only tested by two close friends, and their feedback included:

1. There is not enough navigation information to guide the player.
2. Text and image information is not clearly displayed and delivered.
3. Small icons are difficult to select, making the game a bit cumbersome to operate.
4. Lacking timing system.
5. The interface is too simple.

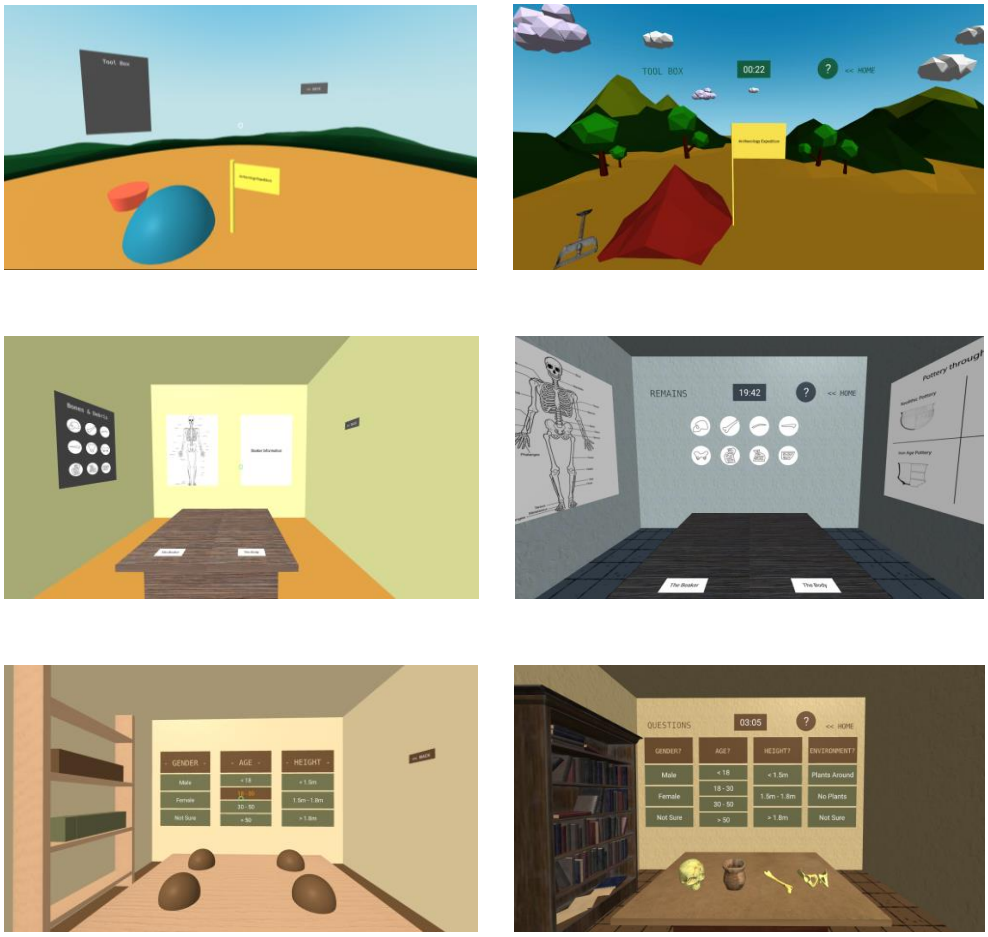


Figure 21 From prototype V1.0 to prototype V2.0

(The left is v1.0, the right is v2.0)

Based on the above feedback, I made a great change to the layout and added some interaction hints to guide the users. For example, icons were much larger and no longer arranged inside a small square board on the left but in lines in front of the view (shown in Figure 21). Prototype V2.0 is mainly evaluated by two persons. One is a senior engineer from Samsung Electronics R&D Institute and the other is an archaeologist from the Achavanich Beaker Burial Project. Their professional feedback mainly covered user experience, information delivery, and program structure. The largest improvement in prototype V3.0 was feedback system and complete archaeology instructions. The player will get error message reminder if he or she didn't operate correctly, and detailed information

about this level will be shown at the end of each level (these were all mentioned before in interaction design section).

The screenshots of the final version are presented in Appendix B and the game can also be directly visited at https://solemom.github.io/Finding-AVA/Finding-AVA/.

Chapter 5

Evaluation

5.1 Evaluation Objectives

The testing aims to evaluate the effectiveness and usability of the game, that is whether the game could help people learn archaeology knowledge and whether it could give the player an immersive and engaging experience. I hoped that the testing could gather a wide range of feedback to get preparation for final implementation in the museum.

5.2 Experiment Design

Based on the above evaluation objectives and in order to collect both qualitative and quantitative data, the experimental procedure was divided into six parts by referring to the evaluation method Victoria and Marian (2012) provided (Guillén-Nieto and Aleson-Carbonell, 2012). All the relevant documents are attached in Appendix C.

1) Ethics

Every participant was given a consent form which stated clearly the purpose of the research, the task for the testing, the right of the participant and the data usage right of the researcher.

2) The pre-experiment questionnaire

This questionnaire aimed to assess the participant's previous knowledge regarding archaeology. It totally contained seven archaeology knowledge points which were abstracted from the information conveyed by my game. The questionnaire basically followed the format of a typical five-level Likert scale item (Likert, 1932) with 1 implying "strongly

disagree" and 5 representing "strongly agree". Specifically, the larger number means that the participant had a better archaeology knowledge background.

3) Informal observation while playing the game with google cardboard

This part was to collect as much information as possible including involvement, enjoyment, difficulties, and duration. The participants would play the game with an iPhone 6 and a google cardboard which could provide them with a VR experience. I applied the "Think Aloud" technique which is often used at evaluation stage in human-computer interaction design (Rogers, Sharp and Preece, 2011), requiring the users to speak out whatever they think, they feel and they did when playing the game. This could help me get more comprehensive and profound information for subsequent qualitative analysis. During the process, a complete video was recorded.

4) Post-experiment questionnaire

The post-experiment questionnaire was the same with the previous pre-experiment questionnaire. I intended to assess the learning outcome by comparing the results of these two stages, thus getting a quantitative analysis in terms of game effectiveness.

5) System usability scale

The system usability scale (SUS) aimed to test the usability of the game (Brooke, 1996). It adopted the standard format which contains ten questions about usability. The participant was asked to score each question on a range of 1 to 5 and I will calculate the overall mark based on this rule: for each odd-numbered row, subtract 1 from the score; for each even-numbered row, subtract its score from 5; the final total score is the result of the sum of all the previously gotten scores multiply 2.5. The higher the mark is, the better the usability is. Normally, a total score higher than 68 means an acceptable usability and lower than 50 means relatively poor usability.

6) Semi-structured interview

In this final interview, more questions about the game including fixed and flexible ones were asked and the participant could give any thoughts, suggestions or comments on the whole experience. It aimed to find out more about the game in a broader way rather than being limited to effectiveness and usability. The voice was recorded at this stage.

5.3 Results and Analysis

5.3.1 The Participants

A total of 12 participants took part in the experiment. They are all postgraduate students in the University of Edinburgh. 25% of them were from engineering background, another 25% majored in design and the remaining 50% were from informatics subjects. Their ages were between 22 to 30 and half of them were female.

5.3.2 The Questionnaire

Before playing the game, the average score of the archaeology questionnaire was 1.65 with minimum of 1.14 and maximum of 2.57. After playing the game, the mean value increased to 4.13 with a range of 2.57 to 5 (shown in Figure 22). From the chart below, it was obvious that the majority of the participants knew little about archaeology before playing, but all of them got different levels of learning progress through the game, with the largest growth of 3.71. Therefore, the overall result of the learning effectiveness was relatively positive. In addition to this, I found that there seemed to be no apparent relationship between the learning efficacy and gender or academic background.

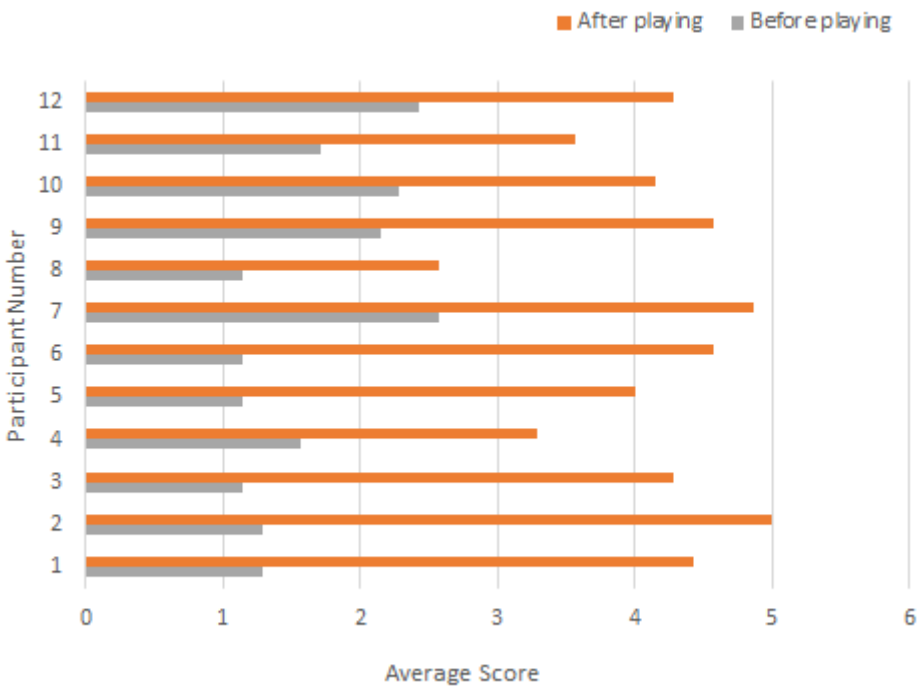


Figure 22 The average score of each participant before and after playing

From the perspective of questions, I also got a satisfying result which indicated a significant improvement in understanding each question (as shown in Figure 23). Especially the first three questions which were mainly imparted through the first “Discover” level, they all achieved the growth larger than 2.5. This may also imply the “Discover” level was the most effective one with respect to learning outcomes.

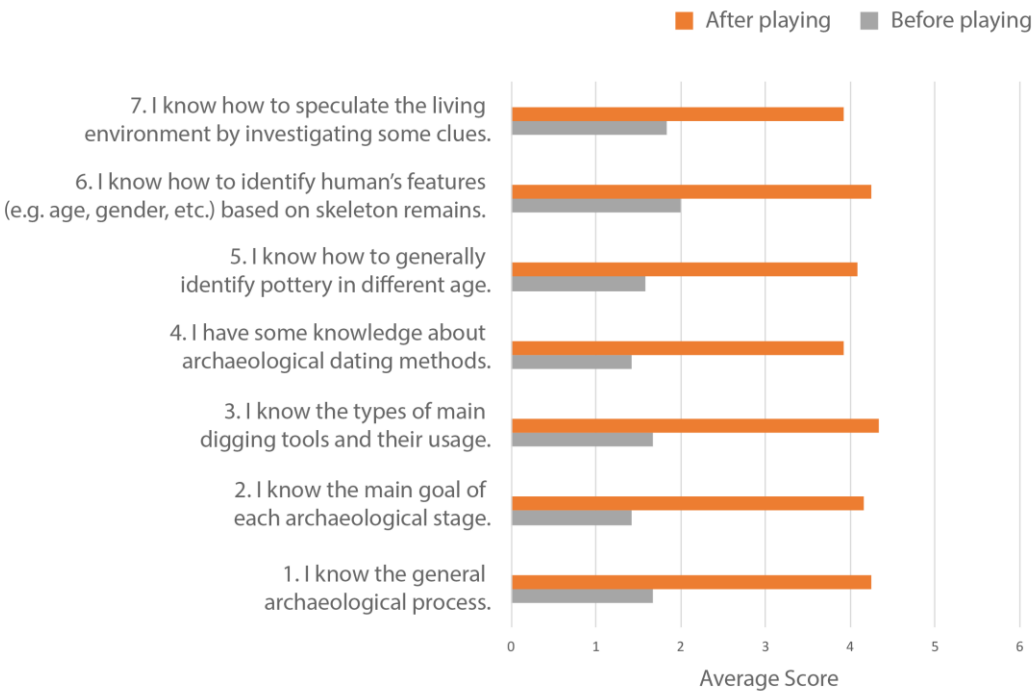


Figure 23 The average score of each question before and after playing

5.3.3 The Observation

This stage required the player to think aloud while playing the game with Google Cardboard (shown in Figure 24). It helped me collect many valuable information, especially in terms of VR experience.

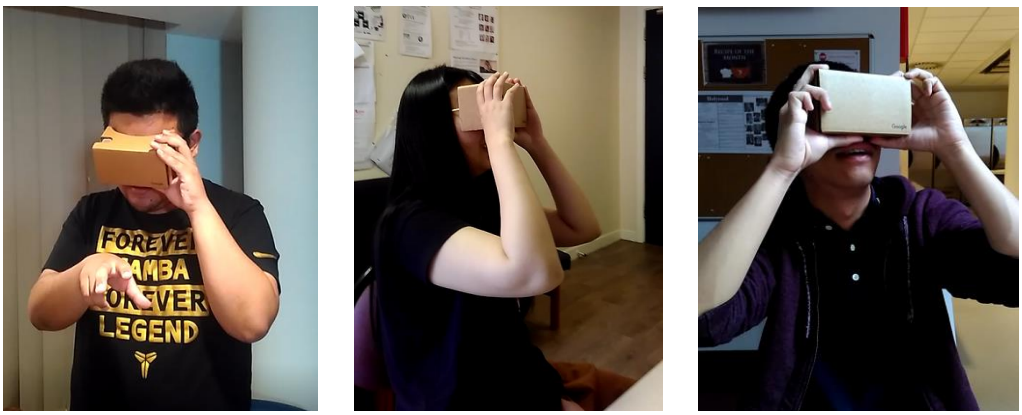


Figure 24 The participants played the game with Google Cardboard

One important thing was the time spent on each level (shown in Table 2). The first "Discover" level took all the participants most of time and it needed an average of 8.58 minutes to complete, whereas the following two levels were both 4 minutes only. The total time for clearing all the levels was around 17 minutes. It is interesting that the length of time and gender were not directly linked although I thought men should finish it faster than women as they generally have more experience in playing games. Another intriguing phenomenon was that students coming from engineering background tend to operate faster than those from other subject areas.

Participant	Gender/ Background	L1 time (min)	L2 time (min)	L3 time (min)	Total time (min)
No. 1	M/ENG	7	**3**	4	14
No. 2	F/DES	7	5	3	15
No. 3	F/INF	10	5	**2**	17
No. 4	M/INF	12	5	3	20
No. 5	M/INF	**12**	**5**	4	**21**
No. 6	F/DES	10	5	**5**	20
No. 7	M/DES	10	3	4	17
No. 8	M/ENG	8	3	3	14
No. 9	F/INF	9	4	5	18
No. 10	F/INF	7	3	7	17
No. 11	F/INF	**6**	4	5	15
No. 12	M/ENG	7	3	3	**13**
Average		**8.58**	**4**	**4**	**16.58**

Table 2 Time spent on each level of each participant
(DES - design, INF - informatics, ENG - engineering)

Through observation, I found that the majority of participants were excited about playing VR game and they learned to use and adapt to Google Cardboard very quickly. However,

they easily got tired because of holding the cardboard and looking around all the time. Therefore, there were only a few participants really enjoying the game. On the other side, there were three players asking the question “how can I move closer” during playing, which implied that the users assumed they could walk around like real world. When I told them the Google Cardboard didn't have the position tracking function, they showed their disappointment obviously. From above, we can see that users like VR and generally had a high expectation on VR experience. For this testing, it apparently failed to give them a sufficient immersive experience. This was partly because of limitations of VR hardware (actually it would work much better with Samsung GearVR), and another reason could be the scene interface lacking enough details to simulate the real environment.

Overall, most participants were interested in searching stuff and exploring puzzles, but some players felt very confused after entering the first level and didn’t know what to do. This uncertainty made them feel anxious and uneasy which I could obviously feel from their expression, movement and intonation. They kept asking “what should I do now” and “what should I do next”. Even there were some hints like glowing objects to guide them, they seemed to be easily ignored. Especially after getting all the digging tools, players had no idea about how to use them and where to dig. This was perhaps one reason leading to longest time spent on this level. However, after the first level, the situation significantly improved. It seemed that the participants began to understand the game mechanic and gradually adapt to it, so they played more and more smoothly. In spite of this, the poor navigation problem exposed by the first level still needs to be properly considered and addressed.

5.3.4 System Usability Scale

The overall feedback gathered from SUS test was positive in general and the average mark of the 12 participants was 75.42 which indicated the usability of the game was quite acceptable. Among all the individual scores, none was under 51, but there were two under 68. Table 3 shows the complete results and the numbers mean the number of participants selecting the corresponding option.

The Questions	SD	D	N	A	SA
1. I think that I would like to play this game frequently.	1		3	**7**	1
2. I found the game unnecessarily complex.	3	**6**	3		
3. I thought the game was easy to operate.		2	2	**4**	**4**
4. I think that I would need the support of a technical person to be able to play this game.	3	3	**5**		1
5. I found the various functions in this game were well integrated.			2	**7**	3
6. I thought there was too much inconsistency in this game.	3	**5**	4		
7. I would imagine that most people would learn to play this game very quickly.			1	**6**	5
8. I found the game very cumbersome to play.	**6**	3	3		
9. I felt very confident playing the game.			3	**6**	3
10. I needed to learn a lot of things before I could get going with this game	**6**	5	1		

Table 3 The result of SUS test

(SD - strongly disagree, D - disagree, N - neutral, A - agree, SA - strongly agree)

From the table, we can easily see that the position of the answer which occupies the largest proportion switches from right to left every two questions and not less than half of the participants gave positive comments on all the questions. This intuitively shows that most of the participants were satisfied with the game on the whole.

However, it is worth noting that there was one person saying he wouldn't like to play this game frequently for the game was not challenging for him. If the game contained more levels with more complicated puzzles, he may like to try. Besides, he also mentioned he felt very uncomfortable with Google Cardboard and he much preferred video games on the computer screen for allowing him to simply sit, press and click. This was another reason for his strong disagreement with the first statement in the SUS. In addition to this, two persons thought the game was not easy to operate and even one felt he definitely need other people's help to complete it. They reflected that it was difficult to target the small cursor to the right spot by controlling your head and this problem became even more obvious in the second

level since it required the player to move the bones and pieces into the correct positions. Moreover, the uncertainty brought by the poor navigation which was mentioned in the previous observation section also aggravated this difficulty and they hoped there would be something guiding them properly rather than exploring alone without any beacons.

5.3.4 The Interview

The interview contained 8 fixed questions, I will list and analysis them one by one.

1) Which level do you like and dislike most? why?

For the favourite level, the complete results are shown in Table 4. Obviously, most of the participants chose the first level as their favourite and the mentioned reasons mainly covered three facets: high aesthetic satisfaction, intriguing puzzle design, and impressive learning outcomes. The third reason also reflected the result mentioned in the previous questionnaire section, that was the first level achieved better learning effects comparatively. There were four participants liking the "Research" level most for it gave them more sense of achievement by practicing their inference skill. This also stayed aligned with my original intention of puzzle design and learning goal in this level. Only one person voted for level 2 because of the lovely body image and easy puzzles. She thought the other two levels were a bit complicated for her and she preferred playing simple games.

Levels	Count	Reasons
Level 1 (Discover)	7	Beautiful and attractive scene Complicated and challenging Novel and interesting like treasure hunting Impressive learning effects More interactive features
Level 2 (Identify)	1	Cute body frame and easy
Level 3 (Research)	4	Needs knowledge and logical reasoning skill Get more sense of accomplishment

Table 4 The results of the favorite level and corresponding reasons

Most people said they had no obvious inclination for the most disliked level, but there were still three persons clearly choosing the second level. The reason was the puzzle was too easy thus boring and the room in the scene was too narrowed, making them feel depressed. They preferred open scenes with a broad view like in the first “Discover” level.

From the results above, we can see everyone’s thoughts varied much. Someone may like it or hate it due to the same reason and this is exactly the case for the second level. Nevertheless, some trends can still be seen from the inclination of the majority. The feedback of this question shows that scene design and puzzle design are particularly important for this game. An appealing scene is the first element to attract people and good puzzles are the next motivation for the player to stay in the game, and they both are essential for learning effectiveness. The proper difficulty level is one key point for a good puzzle and it is a big science. Nobody knows exactly what is “neither too hard nor too easy”. It needs sufficient research, deep thinking, and rich experience.

2) Which level do you spend most of the time? why?

All the participants spent the largest amount of time on the first level. This was basically because they felt confused about operations, rules, and objectives at the beginning. The problem was also exposed during the observation phase. Besides, some of them were curious about the scene and thus spent some time just looking around. Moreover, most of them thought the first level itself was the most complicated level and it required many steps to finish. For example, there were 8 tools in total and you must first find the way to get them and then use them one by one. In spite of this, the majority still prefer the first level.

3) Did you read help information during playing the game? why or why not?

Seven of them read the help information when having no idea about what to do during the first level. Other people didn’t use it. Some even didn’t notice. Those without reading the information told me they hoped to explore the game by themselves and those without noticing said they were focusing on the task. It is noteworthy that one participant felt disappointed when he found that he possibly can’t unlock the puzzle without reading the help information and he thought the help information should not become a must-see content. The game needs to be designed to allow users to explore freely. I quite agree with his point of view and think this problem still exists in the puzzle design. The clue and solution are not

well integrated and there are not enough links between them. Besides, some players suggested that the help information can be more targeted depending on the specific situation the player was currently in.

4) What is your overall feeling about the game?

The participants used many positive adjectives to describe the game including beautiful, pleasing, interesting, fantastic and logical. They also mentioned that the game was well in accordance with archaeology and better developed their interest in learning archaeology compared to boring books. Since the game was not difficult, it was especially suitable for children and museum. However, there was still one participant saying the game was too easy for him because he is an experienced video game player. This goes back to the same problem of balancing difficulty level in puzzle design. For senior players, this game seems not challenging enough.

5) Do you think the game help you learn archaeology knowledge?

All the participants said yes to the question. More specifically, the use of digging tools and human bones identification were the most impressive parts. They also mentioned that the game only involved some basic archaeology knowledge and they hoped it to be deeper. For example, in the second level, the game mainly utilized the shape attribute to identify the beaker age, more features like patterns and colors could be added.

6) Do you agree that “games can be a more effective way of learning compared to traditional educational method like classroom teaching and reading books”?

All the participants agreed with this view and they provided many reasons to explain this. Firstly, games are more interesting and can motivate people to play with it. This is particularly important for those professional and obscure academic fields like archaeology. Without enough motivation, many people wouldn’t like to touch it. Furthermore, unlike books which only output content, games have inputs as well. They allow learners to learn actively rather than accept knowledge passively. Games will also give learners immediate feedback according to their inputs and then the player can learn through these feedbacks. All these points mentioned by participants well supported the background theory for this project and also showed their positive attitudes towards serious games.

7) Do you think VR has given you a different experience?

Eleven players thought VR gave them a more realistic and vivid experience, especially the digging stage. They all agreed that the first level did a better job in terms of VR presentation than the other two levels, but it should be more immersive if allowing players to walk around instead of just look around. One player didn't think VR made a big difference and he even felt a bit dizzy in the end.

8) Do you have other suggestions or thoughts?

Other suggestions mainly covered three aspects: learning purpose, interaction design and overall performance. I summed up in the following Table 5. It was worth noting that one participant suggested making the game be an APP instead of a web link to enhance the stability because the browser automatically drop out when she was playing. I thought this advice was constructive and may help to improve web VR performance.

Aspects	Suggestions
Learning purpose	1. Radiocarbon dating could be more explained 2. Add tool usage description when choosing the tool
Interaction design	1. Disable the icons' selection after using it 2. Dynamically show the digging process 3. Putting the cursor together with the selected objects
Overall performance	1. Too short, add more levels 2. Add music or sounds 3. Make the game be an web APP

Table 5 Other suggestions from participants about the game

Chapter 6

Conclusion

6.1 Discussion

The overall feedback from the evaluation showed a comparatively positive result and the game “Finding AVA” managed to fulfill what it set out to achieve in this project, which was effectively helping people learn archaeology knowledge. Each participant gained some learning progress and agreed that the game better developed their interest in archaeology than traditional education methods like books.

The game embracing mechanics similar to room escape adventures seemed to work well with archaeology. The participants loved to explore like treasure hunting and felt the sense of achievement brought by solving puzzles. In spite of some perplexity caused by the poor guiding system, most players still preferred the first level because of its attractive scene and challenging puzzles. Whereas, the second “Identify” level didn’t win people’s favor due to its depressed scene and too simple puzzles. This contrast indicated two elements, namely scene design and puzzle design, were essential for adventure game. The features of an appealing scene include pleasing style, broad view and details rendering. Good puzzles should have clear objectives and proper difficulty level.

It was impressive to find out that there exists a positive correlation between preference and learning effect. The majority liked the first level most and the learning outcome turned out to be the best as well. Apparently, the degree of favour is largely determined by game design, therefore good game design is crucial to serious games and it directly affects the learning efficacy. Serious games should be good games first, then the educational goals could be reached. Now getting back to the two definitions of serious games proposed respectively by Zyda and Michael which I mentioned in the first chapter, my view is that they actually are not contradictory because they defined it from two perspectives. Zyda focused more on the process, while Michael and Chen put more emphasis on the results. Therefore, Serious games are games achieving educational objectives through entertainment.

In terms of VR, “Finding AVA” failed to create a sufficient immersive VR experience especially in the last two levels, although most of the participants admitted VR’s positive role in facilitating learning. This was partly because of hardware limitations for lacking position tracking function and hand controllers. Another important factor was 3D scene design. It is not simply about putting 3D models together, but simulating a real environment including all the details. A-Frame functioned smoothly and indeed accelerated the development process, but has its restrictions too. I preferred to use original skull and beaker models in the scene which could also help to build more realistic surroundings, but due to their huge size and limited browser capacity, I had to give up. Moreover, it should be better to increase the number of samples for evaluation. 12 participants were far more enough.

6.2 Future Work

Based on feedback from evaluation, this game has many aspects could be improved. Firstly, clearer indications and navigation could be added in order to better guide users. This may be achieved by making help information more specific and instructions more detailed. Secondly, much more efforts should be made on 3D scene design and puzzle design, particularly in the second level. Scenes currently are too simple and tedious, they can be more abundant and realistic by making full use of light, material, UV texturing, etc. Finally, it was still a pity that I failed to complete the mesh registration for 3D scanning models. More work could be done in this field.

In terms of the overall performance, it should be better to change the static program structure into a dynamic one. In other words, the content is generated dynamically based on your needs rather than loaded all together at once. In this way, the browser can run more smoothly and quickly. Another point is considering transforming the web link into an APP, as suggested by a participant, thus enhancing the stability of performance.

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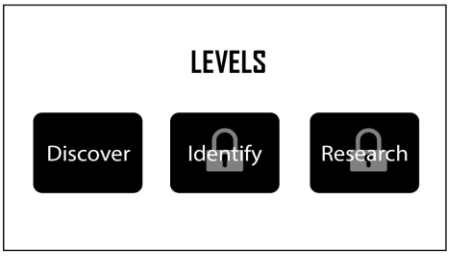
Appendix A: The Story Board

Finding Ava

#1 Get start

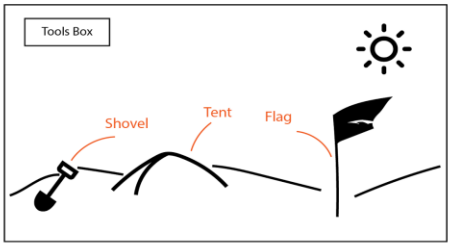
#2 Introduce the background story by playing a video

#3 Convey the mission to the player

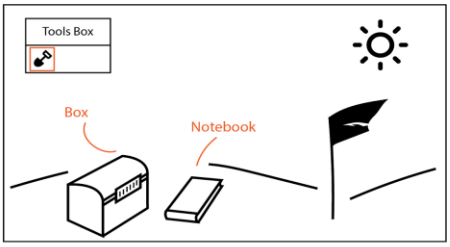


#4 The player needs to unlock the three levels one by one

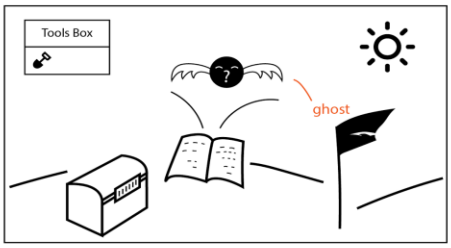
Level 1: Discover



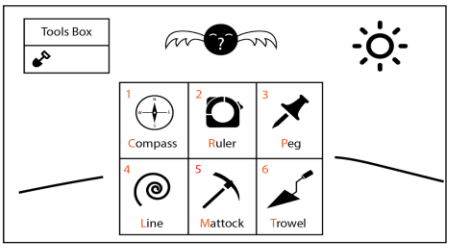
#1 Back to the excavation place and found a shovel



#2 Using the shovel to dig the tent, a box with a 6 digit alphabet lock and a notebook are found.

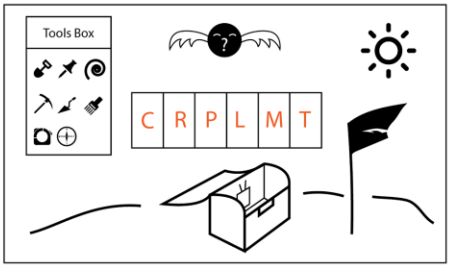


#3 Open the notebook, a small ghost appears. It will introduce related archaeology knowledge after the player solving a puzzle or help the player when he stucks.

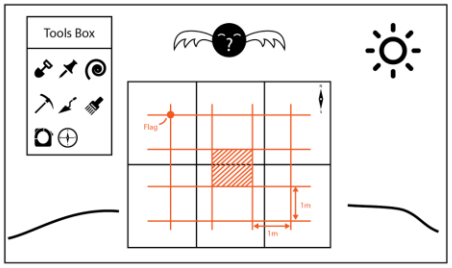


#4 In the notebook, there are 6 pages introducing excavation tools. Each has a number on the opposite side, suggesting the corresponding password location to unlock the box.

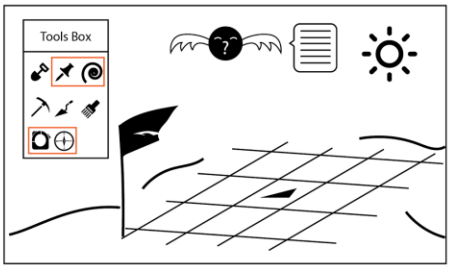
Level 1: Discover



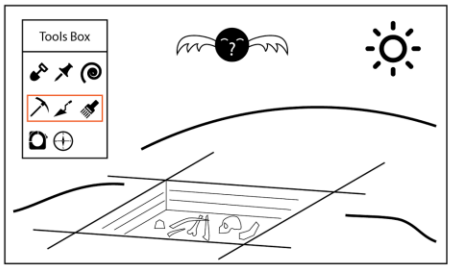
#5 Open the box and get a set of excavation tools.



#6 On the other side of the 6 pages, there are some patterns. Putting together forms a map indicating digging position.

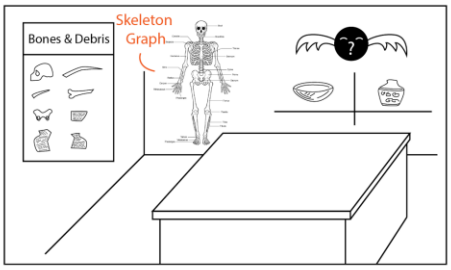


#7 Use campass, measuring tapes, pegs and lines to draw a grid map according to the patterns. The ghost will then tell you more knowledge about it.

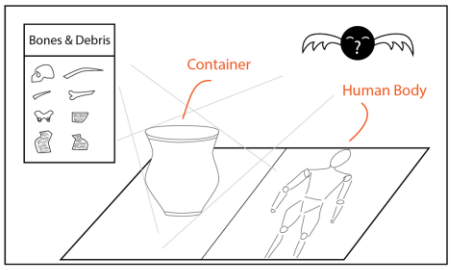


#8 Start to dig at the right position, the player must use the tools in right order. The numbers are the clues. Finally, the zzplayer gets all the bones and debris.

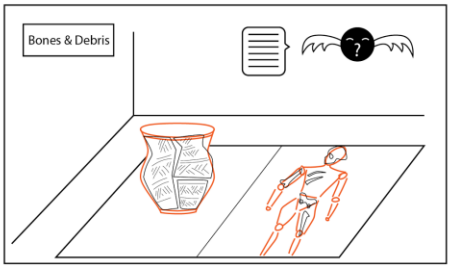
Level 2: Identify



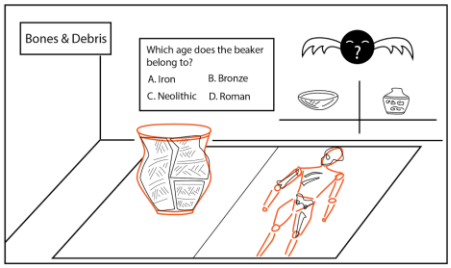
#1 Back to lab, there is a human skeleton graph and some information about pottery on the wall.



#2 Above the desk, there is a 3D projection of a container and a human body frame.

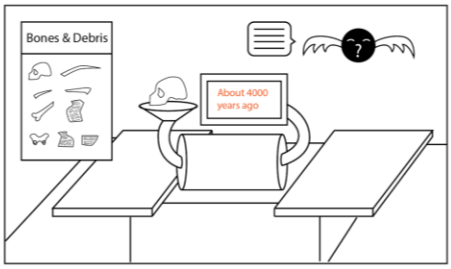


#3 The player needs to put the pieces together to match the projection shape and put the bones in the right human body position according to the skeleton graph.

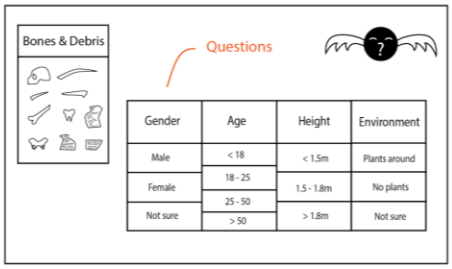


#4 After the reconstruction, a question about dating the beaker to which age pops up. The player needs to answer it based on the information on the wall.

Level 2: Identify

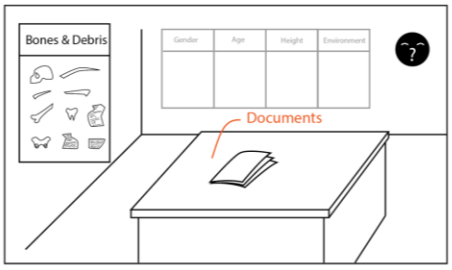


#5 Once answering the question, the desk will split into two parts and radiocarbon detector will appear.

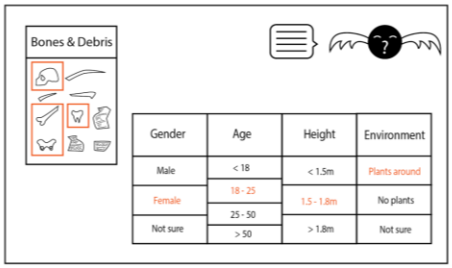


#2 On the wall, there are four questions to be answered. Each option can be pressed.

Level 3: Research

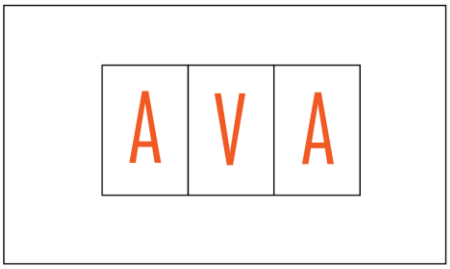


#1 In the research room, the player found some documents.

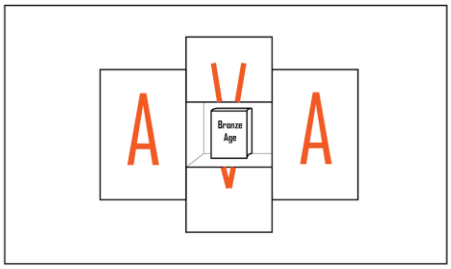


#3 The player should answer the four questions correctly based on the information about bones and the documents.

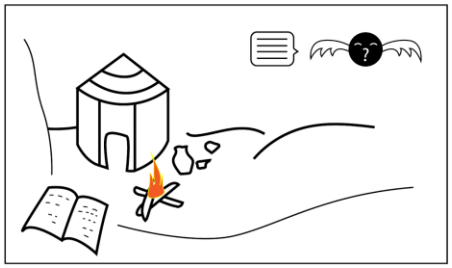
Level 3: Research



#4 Once solving the questions, "AVA" is shown on the wall.

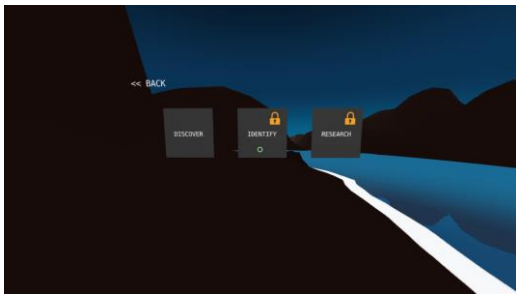


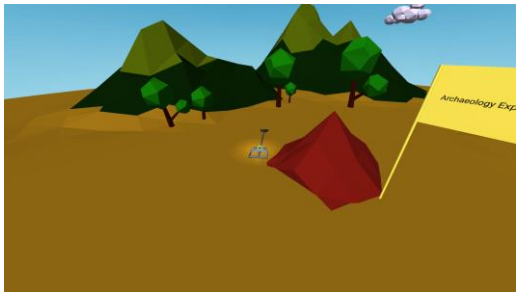
#5 The wall is opened, a book recording life in Beaker Burial Age when Ava lived appears.

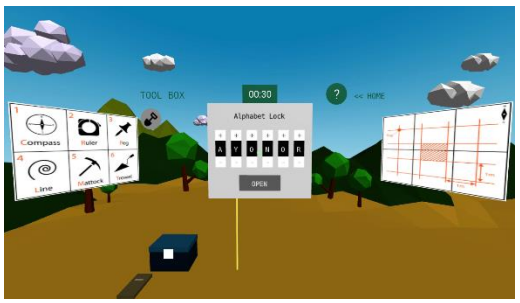


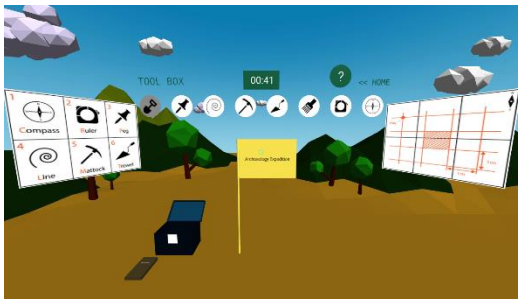
#6 Open the book, there emerge life scenes in Beaker Burial Age in front of eyes.

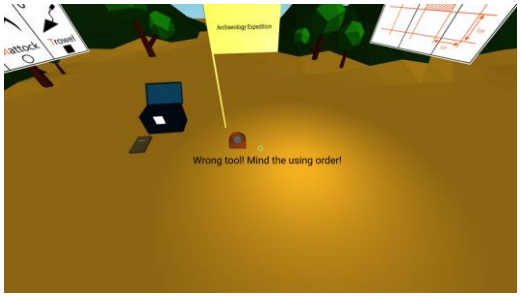
Appendix B: The Screenshots

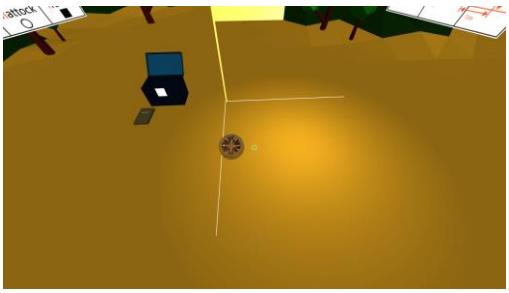


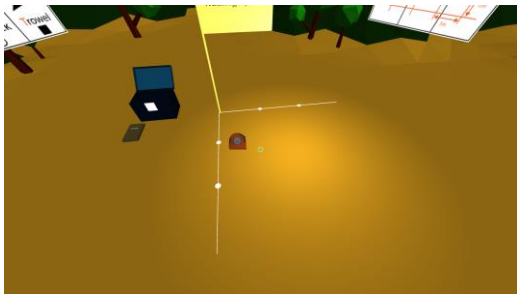


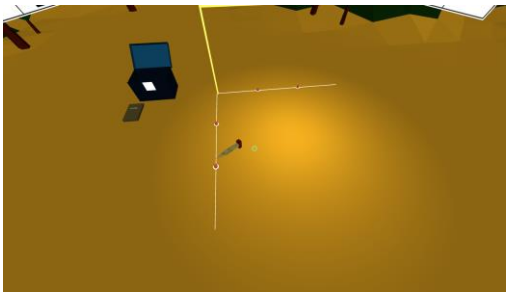


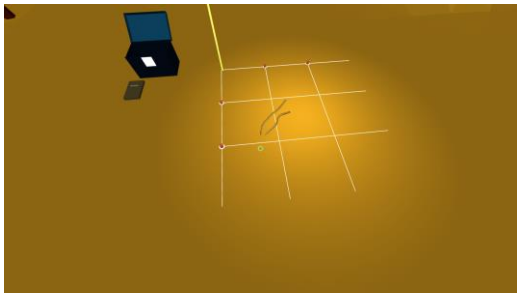


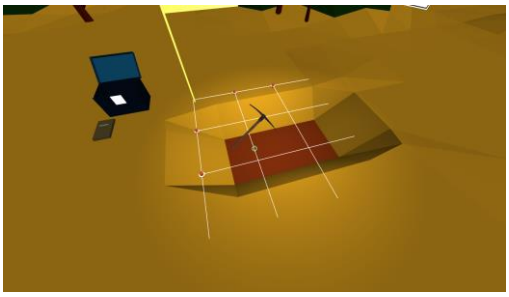

Archaeology Expedition
Wrong tool! Mind the using order!

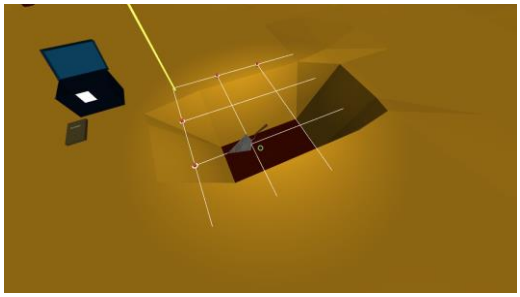


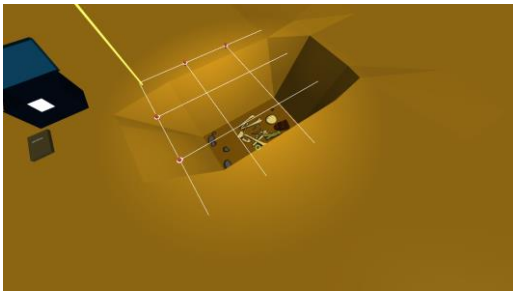


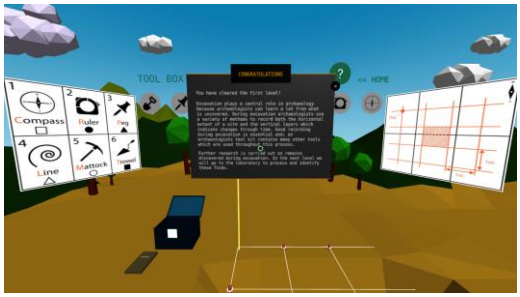


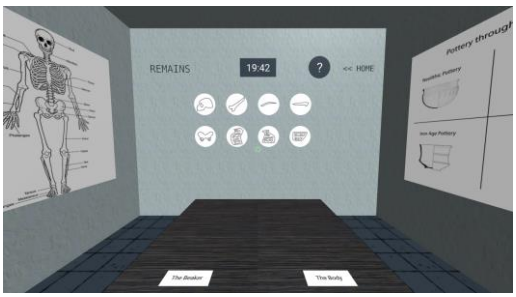


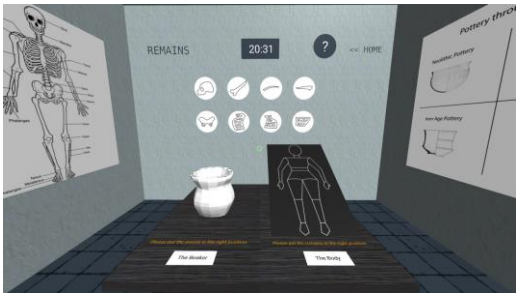


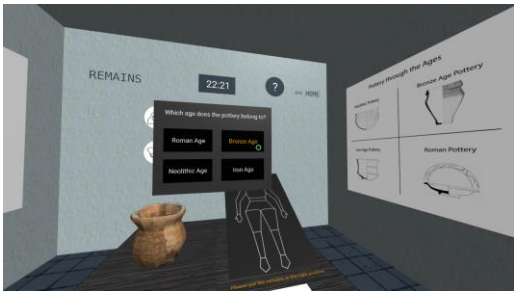


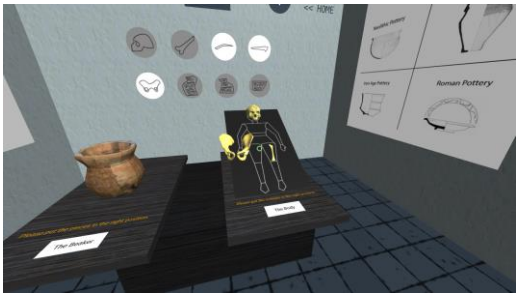


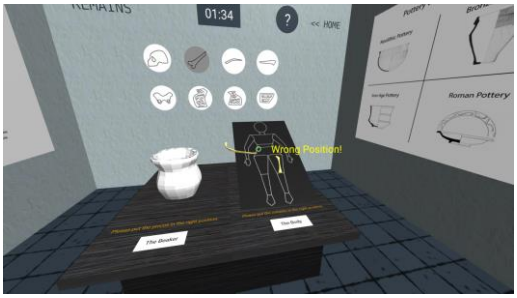

TOOL BOX
CONGRATULATIONS
<< HOME
Compass
Ruler
Line
Mattock


REMAINS
19:42
<< HOME


REMAINS
20:31
<< HOME
The Bracelet
The Teeth


REMAINS
22:21
<< HOME
Which age does the pottery belong to?
Roman Age
Bronze Age
Neolithic Age
Iron Age
Pottery through the Ages
Bronze Age Pottery
Roman Pottery


Roman Pottery
The Bracelet
The Teeth


01:34
<< HOME
Roman Pottery
Wrong Position!
The Bracelet
The Teeth


REMAINS
<< HOME
Pottery through the
The Bracelet
The Teeth


QUESTIONS
03:05
<< HOME
GENDER?
AGE?
HEIGHT?
ENVIRONMENT?
Male
Female
Not Sure
< 18
18 - 30
30 - 50
> 50
< 1.5m
1.5m - 1.8m
> 1.8m
Plants Around
No Plants
Not Sure


04:01
QUESTIONS
GENDER?
AGE ?
Male
Female
Not Sure
< 18
18 - 30
30 - 50
> 50
1.5m -


The bone ridge
Flat
Female
High
Male
Wear on teeth
Many
Old Age
Little
Young Age
Length of long bones
Long
Adults with high height
Short
Children with short height
Width of pelvis
Wide
Female
Narrow
Male


QUESTIONS
04:41
<< HOME
GENDER?
AGE?
HEIGHT?
ENVIRONMENT?
The Skull and Teeth
This skull has a flat brow ridge and teeth that have a little but not very much wear.
Male
Female
Not Sure
< 18
> 50
Plants Around
No Plants
Not Sure
The bone ridge
Wear on teeth
Length of long bones
Width of pelvis


QUESTIONS
05:44
<< HOME
GENDER?
AGE?
HEIGHT?
ENVIRONMENT?
Male
Female
Not Sure
< 18
18 - 30
30 - 50
> 50
< 1.5m
1.5m - 1.8m
> 1.8m
Plants Around
No Plants
Not Sure


QUESTIONS
06:09
<< HOME
AVA


QUESTIONS
06:24
<< HOME

Appendix C: Testing Documents

Consent Form

Title of Project

VR in the Past: Game-based Learning of Archaeological Processes (MSc project)

Name of Researcher

Xiangjun Liu

Consent statement

I am a postgraduate student from MSc Design Informatics and my master dissertation project is exploring VR gamification approach to helping people learn archaeology knowledge.

This testing is a part of the project and it aims to evaluate the effectiveness and usability of this VR game. There are four parts in total. Firstly, you are required to finish an experiment questionnaire which contains 7 questions about archaeology. Secondly, that is playing the VR game with google cardboard. After the game, you are supposed to answer the questions in the pre-experiment questionnaire again and score the System Usability Scale form. Finally, I will conduct a simple interview to ask you more about the game. You can stop at any time if you don't want to continue or just play without any comments.

Completing the testing will take about 20 - 30 minutes, it depends on your game playing time. I will record your data including time spent, voice, video and pictures. If you are not comfortable with it, please tell me in advance.

By signing this form, you agreed that:

1. I have read the above information and have had the opportunity to ask questions.
2. I understand that my participation is voluntary and I am free to withdraw at any time, without giving any reason.
3. My recording data could be used in the final write-up of the project.

Signature:

Date:

Experiment Questionnaire

Gender: _____ Age: _____

	Strongly Disagree				Strongly Agree	
1. I know the general archaeological process.	1	2	3	4	5	Before playing
	1	2	3	4	5	After playing
2. I know the main goal of each archaeological stage.	1	2	3	4	5	
	1	2	3	4	5	
3. I know the types of main digging tools and their usage.	1	2	3	4	5	
	1	2	3	4	5	
4. I have some knowledge about archaeological dating methods.	1	2	3	4	5	
	1	2	3	4	5	
5. I know how to generally identify pottery in different age.	1	2	3	4	5	
	1	2	3	4	5	
6. I know how to identify human's features (e.g. age, gender, etc.) based on skeleton remains.	1	2	3	4	5	
	1	2	3	4	5	
7. I know how to speculate the living environment by investigating some clues.	1	2	3	4	5	
	1	2	3	4	5	

System Usability Scale

	Strongly Disagree				Strongly Agree
1. I think that I would like to play this game frequently	1	2	3	4	5
2. I found the game unnecessarily complex	1	2	3	4	5
3. I thought the game was easy to operate	1	2	3	4	5
4. I think that I would need the support of a technical person to be able to play this game	1	2	3	4	5
5. I found the various functions in this game were well integrated	1	2	3	4	5
6. I thought there was too much inconsistency in this game	1	2	3	4	5
7. I would imagine that most people would learn to play this game very quickly	1	2	3	4	5
8. I found the game very cumbersome to play	1	2	3	4	5
9. I felt very confident playing the game	1	2	3	4	5
10. I needed to learn a lot of things before I could get going with this game	1	2	3	4	5

Semi-structured Interview Questions

1. Which level do you like and dislike most? Why?

2. Which level do you spend most of the time? Why?

3. Did you read help information during playing the game? why or why not?

4. What is your overall feeling about the game?

5. Do you think the game help you learn archaeology knowledge?

6. Do you agree that “games can be a more effective way of learning, compared to traditional educational method like classroom teaching and reading books”?

7. Do you think VR has given you a different experience?

8. Do you have some other suggestions or thoughts?