ARticular: An augmented reality game concept for a museum setting

Sophia Spivak

An exegesis submitted to
Auckland University of Technology
in partial fulfilment of the requirements for the degree of
Master of Communication Studies (MCS)

2015

School of Communication Studies

Attestation of authorship

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning.

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Date

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Acknowledgements

First and foremost, I would like to thank my supervisor, Abhishek Kala, for the guidance, encouragement and advice he consistently provided throughout the project.

I would like to express my gratitude to the AUT University School of Communication Studies for granting me the postgraduate scholarship with which to undertake this study. To Gudrun Frommhertz, for encouraging me to pursue this path of research. To Dr Frances Nelson, for her uplifting support during my moments of self-doubt. Also to Dr Welby Ings who provided guidance for refining the structure of the creative work.

I am indebted to the members of my expert reference group who provided me with inspiration, critique and insight: Nils Pokel and Johnny Hui of the Auckland War Memorial Museum; iOS developer Oleg Chernyshenko and designer Svitlana Amelina for feedback on my interface design ideas; and Taura J. Greig for his assistance in developing aspects of the AR functionality in Vuforia. I would also like to thank the team at Imersia for the initial chats we had that gave me insight into the exciting world of augmented reality.

To all of my friends who were there to bounce ideas off, proofread my work, or offer a helping hand in times of need; particularly to my friend and fellow AUT student, Anna Sazykina, for inspiring me to undertake postgraduate study and leading by example.

Finally, to all my family members for their endless and unconditional love and support. Especially to Mom and Dad, for instilling in me an appreciation of the importance of education and for supporting my decision to go back to study.

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Terminology

Definition of terms and abbreviations used in this exegesis.

Term	Description
App	A term used to describe a computer application for smartphones and other devices. Typically this is a small, self-contained piece of software designed for a particular purpose, such as a game.
Augmented Reality (AR)	A technology that allows virtual objects to be blended into the user's perception of the real world, using devices such as smartphones or head-mounted displays.
Head-Mounted Display (HMD)	An electronic device worn on the user's head that provides a sense of immersion into the environment displayed. Most HMDs available today are in the shape of a helmet or goggles.
Human Computer Interaction (HCI)	A discipline concerned with the study and design of computer systems for human use, with an emphasis on making technologies easy and productive for their users.
Smartphone	A mobile phone with the advanced functions of a computer, such as internet connectivity, media players, a digital camera, GPS navigation, and various third-party apps.
User	A person who uses or operates something, such as a mobile application, a piece of equipment, or a service.
User Experience (UX)	A person's perceptions and responses that result from the using something, such as a mobile application, especially in terms of how easy or pleasing it is to use.
User Interface (UI)	Typically this refers to the visual aspect of a software application that allows the user to interact with the device using graphical icons and indicators, such as windows, icons and menus that can be manipulated.

Abstract

ARticular is an exploration into the use of game design and augmented reality in creating interactive experiences for museum visitors. In this practice-led research project, the creative work undertaken focuses on the creation of a design concept of an augmented reality puzzle game, envisioned to be installed in a children's discovery centre at the museum, and designed to facilitate creative engagement and social interactions among its visitors.

This practice-led thesis is comprised of 50 per cent creative work supported by a 50 per cent written exegesis. The creative outcome of this research is presented in the form of a game concept, attached in a separate document. The written exegesis presented herein contextualises this work in relevant literature, rationalises the methodological approach, and describes the experiences and challenges that were encountered in the creative process.

Note

The thesis is comprised of two parts. One part is a document containing the creative work developed through the research inquiry. The second part is the written exegesis presented herein to support the creative work.

The exegesis uses a first person active voice in specific areas, such as the description of the design process in Chapter 4, primarily for sharing my own experiences and reflections. Using the first person voice in this context gives a sense of ownership to discussions about the idea formation process.

To avoid unnecessary repetition, abbreviations were used, such as AR for augmented reality, and W&W for the Weird and Wonderful gallery.

The appendices of this exegesis present a selection of the photographs, images, sketches and drawings created or acquired in the process.

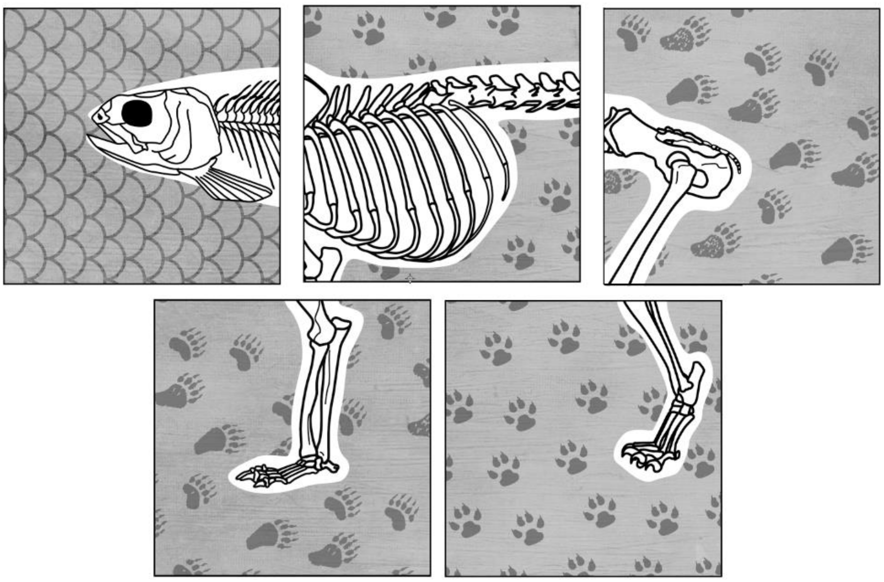

Figure 1. Puzzle pieces.

Introduction

Increasingly, the role of museums is shifting from being places of cultural preservation to being spaces for participative experiences for their visitors (Jun & Lee, 2014). It is becoming apparent that the museum-goers are willing to be personally engaged and entertained during their visit (Burton & Scott, 2003). To actively engage the visitors, museums must provide a range of experiences. Thus, many museums are now seeking the "Holy Grail of interactivity" (Hawkey, 2004, p. 3) to engage their audiences.

One potential way to provide interactive museum experiences is to offer game-based activities through virtual platforms. Since museums are public forums, visitor interactions in the museum environment are predominantly social (Mery Keitel, 2012). This is especially relevant for children's discovery centres inside museums, where the age of the children means that they usually visit with adults, such as parents and grandparents (J. Hui, personal communication, October 10, 2014). Interactive, digital games can be designed to support social interactions between the children themselves and their accompanying adults, and to provide the opportunity for intergenerational knowledge sharing.

Recent developments in digital technologies provide new pathways for the interactive engagement of museum visitors. One of the new branches of digital platforms being explored in the museum community is augmented reality (AR). AR is a predominantly visual technological platform that mixes the physical world with digital content. To date, common applications of AR within a museum environment include interactive tour guides (Damala, Cubaud, Bationo, Houlier, & Marchal, 2008), mixed-reality installations where physical and digital content merges (Basballe & Halskov, 2010; Kondo et al., 2007), and educational games (Ciurea, Coseriu, & Tudorache, 2014; Thian, 2012).

However, the unique affordance of AR in allowing users to see the digital content superimposed over the real world, without obstructing it entirely, facilitates face-to-face communication between users (Billinghurst, Kato, Kiyokawa, Belcher & Poupyrev, 2002). Consequently, it is interesting to explore the potential of game design with AR in creating interactive experiences that facilitate communication and collaboration between museum visitors, particularly children and family groups.

Through practice-led research, my study explores the various affordances and challenges of AR and game design in creating an interactive experience for museum visitors. In this exegesis, I describe my experience in developing the concept of *ARticular*, an AR game for children in a museum setting.

Aim

My aim is to design an interactive museum activity that encourages creative engagement and social interaction through the use of AR and game design. Using a real-world museum site as a hypothetical setting, the design of this game is bounded by the social and physical context of the children's discovery centre at the Auckland War Memorial Museum, and is targeted towards children aged 4 to 8.

This study uses the creative-production project methodology developed by Scrivener (2000). Unlike standard problem-based research approaches, the creative-production project does not set out to solve a single problem or answer a single question (Scrivener, 2000). Rather, Scrivener defines creative-production projects as those which have a topic of interest as well as a creative objective, with the former informing the latter. For instance, in my study the topic of interest is: interactivity in the museum, and my creative objective is to design an AR game concept. As an exploratory study, it does not seek to yield a "final" solution, therefore the research does not involve validation of the concept through user testing.

Scope

It is important to note that, as a creative-production project, the scope of the research presented herein is inherently broad and multidisciplinary. Scrivener (2000) explains that "multiple issues and goals may be appropriate and it should be acknowledged that these may change, grow, and be given different emphasis as the work proceeds" (p. 12). My research inquiry is therefore driven by my ongoing and evolving experiences in the role of the designer of *ARticular*, and is likely to gain more breadth in the process, drawing on various disciplines to inform the design creation. The study explores multiple stages and aspects of the design process, including: the game ideation, experience design, content creation, technical feasibility testing and more.

This study is concerned with the overall concept design of an AR game, and not with the technicalities of programming an AR application. The creative outcome of this thesis is limited to a visual presentation of the game concept only, not of a working prototype for evaluation of user engagement. While the W&W gallery in the Auckland Museum provided the contextual setting for my project, the concept developed as part of this study is not intended to be deployed on the museum floor as an outcome of this research.

Significance of the study

The exegesis addresses various considerations arising from designing an AR game. This may provide an insight for both game designers and digital designers wanting to follow similar approaches. Furthermore, by presenting an original concept of a museum-based AR game, this study may also be of value to museum curators interested in utilising emerging digital platforms to enrich visitor experiences, particularly for younger audiences.

Exegesis structure

According to the AUT Postgraduate Handbook (Auckland University of Technology, 2015), in practice-led research where the major output is an artefact of creative work, the role of the exegesis is to "elucidate and clarify the relationship between the central concept, key contexts, focus and methodology of the creative work, thereby setting the thesis in its relevant critical context" (p. 109).

The exegesis is divided into six sections:

1. Positioning the researcher: This chapter outlines the background of the researcher in relation to this study, and articulates the origins of the project. This chapter also defines the researcher's relationship with Auckland Museum, the setting used to provide context for *ARticular*.

2. Methodology: This chapter introduces and justifies the creative-production project methodology. It then describes the research design with reference to specific methods and processes employed in the production of *ARticular*.

3. Review of contextual knowledge: This chapter provides an overview of knowledge pertaining to my study, to place the creative work in its relevant context. The role of interactive technology in museums is described, the use of game design as a tool for visitor engagement is explained, and the field of AR technology is introduced.

4. Concept design process: This chapter documents the process of creating *ARticular*, describing the choices, concerns and challenges encountered. Concurrently, it presents additional contextual knowledge acquired in the process to inform the design.

5. Description of the final concept: The chapter presents an exposition of the final game concept and provides final reflections on outcome of the creative-production project.

6. Conclusion: The closing chapter provides a summary of the research, its limitations, and discusses potential areas for further study.

Chapter 1. Positioning the researcher

Over the last 10 years, I have been working in a communications designer role for a number of different organisations, and have been involved in a number of diverse projects. During this time, I have had the opportunity to focus on a variety of niches within the field of visual design, including graphic, web and mobile application design. With time, I gained an appreciation for the need to continually evolve and develop my understanding of the various emerging media forms, given the rapid pace of change within my chosen field. It is for this reason that I decided to embark on this journey of postgraduate study in digital media communications to bring myself up to date with the emerging trends within my field, and to challenge myself to expand my professional knowledge, particularly in the areas of interactive and game design.

While completing a Postgraduate Diploma in Communication Studies in 2013, I took a particular interest in an assignment involving the development of an interactive kiosk for a fictitious museum. In the course of pursuing this task, I decided that the kiosk's primary function – the effective communication of information to the museum visitor – would be better achieved if the kiosk was "gamified" (Deterding, Dixon, Khaled, & Nacke, 2011), meaning the information would be conveyed with the aid of interactive games, encouraging active participation. Eventually, this assignment led me to pursue a further interest in the design of interactive learning experiences in museums, a topic I decided to pursue for my Master's degree research the following year.

The impetus for this project

In order to get a hands-on feel for my research topic, I dedicated some time to investigating existing interactive installations in the Auckland Museum. Over the summer before the commencement of my Master's degree, I spent considerable time in the museum, researching exhibitions for relevant research ideas and innovative approaches to the subject. Perhaps unsurprisingly, a number of interactive activities were to be found in the children's discovery centre, known as the "Weird and Wonderful" (W&W) gallery. Here were several interactive digital exhibits, including iPads loaded with educational apps about the natural world (Figure 2), video microscopes, and interactive projections facilitated through Xbox Kinect technology.

Figure 2. iPads with educational games at W&W gallery.

What piqued my interest the most, however, was an AR station comprised of physical blocks that are intended to be held in front of a provided (fixed position) iPad, thus triggering an AR overlay. This overlay, displayed over the visible physical blocks, showed various marine life attached to the block(s), as if the latter were being studied under a microscope (Figure 3; for additional photographs, see Appendix A).

Figure 3. AR “microscope” station at the W&W gallery.

I found this installation to be an exciting new way to present information. At the same time, I also identified what I consider to be a certain limitation of the application in the rather shallow form of interaction it affords. The application only displayed additional information in AR without further pathways of engagement. Nevertheless, the combination of physical and digital interactivity appealed to me as an interesting and highly relevant research area, and I became inspired to explore the topic further by designing my own AR experience, with increased emphasis on playful engagement, creativity and collaboration for visitors.

In order to ground the project and set appreciable limits, I determined to stick with the W&W gallery as a unique and particular setting for my practice-led research project. This meant that my design would have to work within the constraints of the physical space and the gallery's established target audience. After contacting the museum to express and explain my research interest and intent, I had several meetings with key museum staff which helped further define the aim of this thesis, as well as inform the concept design by identifying several key visitor engagement objectives, elaborated in Chapter 4.

Relationship with the Auckland Museum

It is important to note at this point that this study is exploratory and independent, and is not research commissioned by the Auckland Museum, nor treats the Auckland Museum as the "client". The museum has not dictated the objective of this study. The W&W gallery plays the role of a contextual hypothetical setting, and any input from museum staff should be considered as consultations with subject experts.

The museum also graciously provided me with several pieces of information that I required for the concept design, such as the museum's visitor demographics and W&W target audience profile, as well as providing expert feedback on my concept design.

Chapter 2. Methodology

The methodological approach and research design of my study are presented in this chapter, with reference to specific processes and methods employed in the production of *ARticular.* The application of these methods in my research is further demonstrated in Chapter 4.

Practice-led research

This is a creative practice-led project (Candy, 2006), meaning that the practice constitutes a critical part of the thesis. In practice-led research, the researcher becomes involved in an ongoing, self-reflexive engagement with the work. This makes practice-led research a unique paradigm is which creative practice serves as the driver of the research process, as well as its outcome (Hamilton & Jaaniste, 2009).

As was highlighted in the introduction to this exegesis, this study explores the potential of game design and AR in a museum setting, with a focus on the social and motivational factors. To achieve this, it develops a concept of an AR puzzle game for a children's gallery in the Auckland Museum. The process of designing any game is a highly complex one, dealing with multifaceted bodies of information, and there is no single prescribed step-by-step process for the game designer to follow (Crawford, 1984). Therefore, it was important from the beginning of my research to design an approach that would allow for a high level of flexibility and reflection during the development of the work. Scrivener (2000) has formulated a research model that accommodates such requirements, which he has labelled a creative-production project. He describes creative-production projects as being inventive, original works where multiple ongoing issues, concerns and interests are explored and realised through the production of creative artefacts.

According to Scrivener (ibid.), in a creative-production project the research commences with a topic of interest and a creative objective. The topic of interest informs the creative objective. In my study the general topic of interest is interactivity in a museum setting and my creative objective is to design an AR game concept. Therefore, the overall creative-production project focuses on designing an AR game that provides interactive experiences for museum visitors. However, Scrivener also stresses that both the topic of interest and the creative objective may change throughout the course of the research. Although in my practice they generally remained the same, a slight transition occurred as the research focused more and more on designing for children, which entailed new interests in topics related to child development.

Reflection plays a central role in the creative-production process, Scrivener (2000) argues, because critical awareness keeps the project open to changes and improvements. Scrivener employs Schön's (1983) concepts of reflection-in-action and -practice (RIAP) and reflection-on-action and -practice (ROAP). RIAP refers to the ability to think about what we are doing while we are doing it, to "think on our feet" to drive the project forward; it is an immediate reflection happening while an action is in progress. In contrast, ROAP refers to taking the time after the event to "learn from experience" (Scrivener, 2000, p. 10). Immediate RIAP informs the construction of retrospective ROAP (Figure 4). Together, these two processes as part of the creative-production project constitute the everyday working process of my research. As described by Scrivener (2000) and illustrated in Figure 4 below, "the process spirals through stages of appreciation, action, and reappreciation, whereby the unique and uncertain situation comes to be understood through the attempt to change it, and changed through the attempt to understand it" (p. 7).

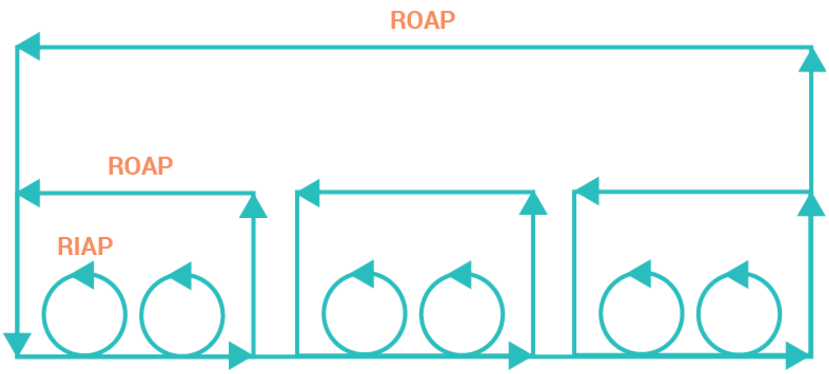

Figure 4. Reflection in and on design episodes and projects.
Adapted from "Reflection in and on action and practice in creative-production doctoral projects in art and design" by S. Scrivener, 2000, *Working Papers in Art and Design 1*.

Research design and methods

A collection of methods associated with creative production have been employed in this study. Figure 5 below shows some of the methods and techniques I used in this research.

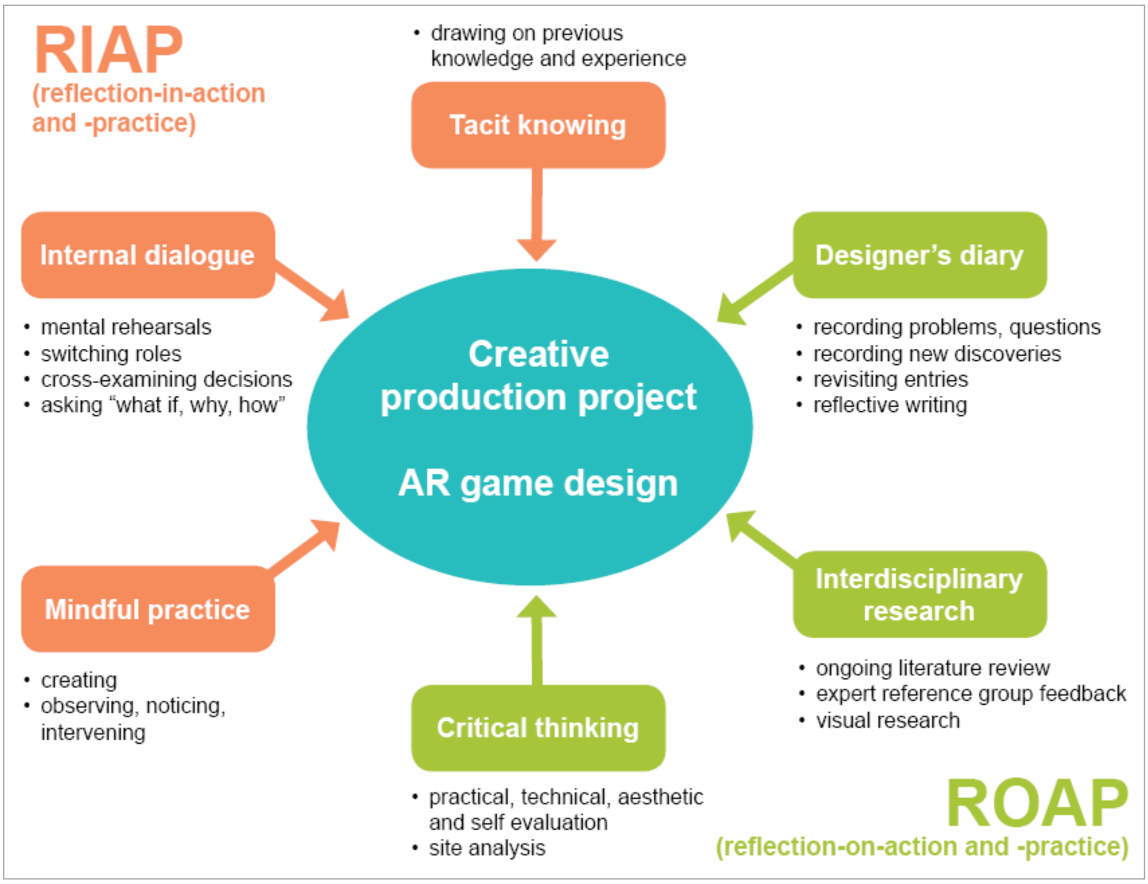

Figure 5. Diagram of the methods used in this study.

Due to the multitasking nature of the creative-production process, the methods are used intermittently, rather than in a linear fashion, to drive the project forward. Below, I offer a further explanation of some of the methods used to clarify their meaning.

Tacit knowing: As a design practitioner, I often make decisions based on my previous experience and knowledge, without being consciously aware of doing so. This can be described as *tacit knowledge*, the hidden experience that invisibly informs creative decisions (Polanyi, 1966). For an experienced designer, years of practice can lead to a certain internalising of accumulated knowledge. This internal knowledge repository then provides the ability to make design moves intuitively, as opposed to referring to external guidelines to inform the decision-making process.

Internal dialogue: In the process of game creation, the designer is potentially playing the roles of a subject matter expert, a programmer, an artist, a user interface designer, a project manager and more. Being involved in this ongoing process of role-switching during my project, I would naturally engage in internal dialogue that would enable me to multitask while maintaining consistency across the different aspects of the game, and to constantly question the decisions I made through various disciplinary lenses.

Mock-ups and technical testing: Draft artwork of animal anatomy – both skeletons and overlays - was created in Adobe Illustrator. This artwork was then printed out, and used for design evaluation and experimentation, such as testing of possible layouts, shapes and sizes of the puzzle pieces. Puzzle pieces were modelled and developed using Unity 3D software and AR program Vuforia SDK. Testing also often involved technological inquiries related to designing for AR, such as the augmentability rating of the artwork, explained in Chapter 4.

Designer's diary: Keeping a diary allowed me to record information relevant to the various stages of project development. Newbury (2001) contends that keeping a diary is a valuable process for its role as "a coherent central record of project ideas, information and activities, and its use as a stimulus for reflective thinking" (p. 8). When the designer looks back through the diary, new insights may trigger further explorations in research. Thus, the diary is an aid to reflective practice. In my research, notes and ideas developed or accumulated during the creative-production process were saved primarily within a digital notebook using Evernote software (Evernote Corporation, 2015), as well as in physical notebooks. Evernote also contained also visual documentations including photographs, scanned sketches, screenshots, and video recordings of my AR experiments. I used the online tool Pinterest (Pinterest Inc., 2015) as a place to collect my visual research, such as examples of puzzle games. Larger files, such as iterative design versions, were saved within a Dropbox (Dropbox, Inc., 2015) account. As per the earlier recommendation by Newbury (2001), I would periodically review my repositories of material, reflecting on it to inform further work.

Site analysis: Site analysis involves collecting relevant information about a particular site, and analysing it to inform a new design. In the context of this research, site analysis concerns the W&W gallery as a unique setting for my concept design. The first site analysis occurred in the earliest stage of my research, when I visited the gallery to familiarise myself with the existing digital content and activities within it. In doing so I was able to identify some potential issues with an existing AR exhibit as described on page 5, which led me to frame the topic of interest and creative objective of this study. Using the W&W gallery as a setting for *ARticular* also meant there were certain unique site-related factors to take into account when designing the concept, such as its physical environment and visitor demographics. Therefore, later in the project, another round of site analysis was undertaken in order to create a concept that is responsive to the needs of the museum.

Expert reference group: Throughout the creative-production process, discussions were held with an expert reference group with the aim of providing feedback on the developing concept. The group comprised five individuals from relevant backgrounds, as shown in Table 1. During the design process, useful suggestions and feedback about the concept of *ARticular* were provided by key staff of Auckland Museum who specialise in museum family programmes and digital strategies. I also engaged the services of a skilled computer programmer to develop an important part of the AR functionality in Unity, to confirm the technical feasibility of my idea. Moreover, I discussed various aspects of the user interface with a UI designer and iOS mobile application developer.

Table 1

Members of the expert reference group

Name	**Professional Background**
Nils Pokel	Digital Strategist - UX/Emerging Technologies, Auckland Museum
Johnny Hui	Family and Early Years Programmer, Auckland Museum
Taura J Greig	Computer Game Developer
Oleg Chernyshenko	iOS Mobile Developer, Game Developer
Svitlana Amelina	UI Designer, Children's Illustrator

Conclusion

The primarily system of inquiry employed in this study can be described as a creative-production project (Scrivener, 2000). The research design focuses on the various ongoing issues, concerns and interests that are explored and realised through the production of the creative work. To progress the research project, I employ tacit knowing, reflection in and on action and practice, and discussions with the expert reference group. Furthermore, as the project unfolds, I engage in an ongoing contextual review of literature pertaining to emerging topics of interest to inform creative decisions. An open-ended exploratory methodology described herein facilitates a research design that can respond to the diverse needs of the project, which is inherently broad in scope and multidisciplinary.

Chapter 3. Review of contextual knowledge

While this chapter provides a brief overview of contextual knowledge relating to this study, it must be emphasised that additional contextual literature was perused as necessary throughout the entire creative-production process, and is placed in the relevant contexts in Chapter 4.

Interactivity in the museum

Recently, an increasing number of museums worldwide have experienced a shift from being places of cultural preservation to being spaces for participative experiences and engagements of their visitors. As pointed out by Jun and Lee (2014), “the role of museums has shifted from collection-driven institutions to experience-centred environments”. It is becoming apparent that the museum-goers are willing to be personally engaged and entertained during their visit (Burton & Scott, 2003). Thus, many museums are now seeking the "Holy Grail of interactivity” (Hawkey, 2004, p. 3).

According to McLean (1993), interactive museum exhibits can be defined as “those in which visitors can conduct activities, gather evidence, select options, form conclusions, test skills, provide input, and actually alter a situation based on input” (p. 93). It means the exhibit responds to the visitor’s actions in some way.

There are multiple studies on visitor experiences with interactive exhibits that suggest that interactivity in general can promote engagement, improve understanding of the exhibit and even increase memory retention of the information for the visitor (Allen, 2004). For example, Richards and Menninger (1993) evaluated interactive installations in a museum and found that they significantly increased the amount of time visitors spent there. Borun and Dritsas (1997) identified the integration of interactive design into museum exhibits as a key feature in fostering family learning in the museum.

Following the quest for interactive visitor experiences, there has been a significant interest among museums and scholars in exploring the new ways in which visitors can be engaged using digital technologies (Hawkey, 2004). Various digital platforms are being used in museums to facilitate onsite interactivity, such as touch-screen kiosks, multitouch tabletops, location-aware museum guides, personalised mobile applications, and games.

Games

One potential way to provide rich and interactive museum experiences is by offering game-based activities. Games in general contain elements that support engagement and motivation (Kapp, 2012; Schell, 2008). Hawkey (2004) argues that museums must provide experiences that are "stimulating, enjoyable, relevant and appropriate for the visitor" (p. 17). Csikszentmihalyi and Hermanson (1995) argue that ideally, museum experiences should initially draw the visitor through curiosity and interest, and keep them engaged through a state of flow, in which the visitor becomes absorbed in the activity through physical and mental concentration. According to Salen and Zimmerman (2003), being in a state of flow means being engaged in a rich and meaningful experience with the activity.

Flow can occur in various activities, and can be subjective to the individual (Salen & Zimmerman, 2003). However, it is something that can be attempted through game design (Kapp, 2012; Salen & Zimmerman, 2003). To promote a state of flow in games, the challenges provided in the game must be designed to closely match the player's skills, so that the player is neither frustrated by the difficulty, nor bored by the simplicity. As an enjoyable experience, flow increases intrinsic motivation for continuing to play the game. Kapp (2012) describes intrinsic motivation as an internal factor, such as when a person undertakes an activity "for its own sake, for the enjoyment it provides, the learning it permits, or the feeling of accomplishment it evokes" (p. 52). In contrast, extrinsic motivation comes from external factors, such as a prize, a badge, or the praise and admiration of others (Kapp, 2012).

Csikszentmihalyi and Hermanson (1999) also discuss extrinsic and intrinsic motivations in museum engagement, and argue that museums must provide highly intrinsically motivating experiences in order to engage the audience. Games can be designed to provide intrinsic motivation through elements such as fantasy or satisfaction from overcoming challenges.

Furthermore, games increase motivation for learning (Kapp, 2012), and they can also provide an entertaining way to support social interactions (Horn et al., 2012). Since museums are public forums, visitor interactions in the museum environment are mainly social (Mery Keitel, 2012). This is especially relevant for children's galleries inside museums, where the age of the children means that they usually visit with adults, such as parents or teachers. Multiplayer game-based activities can facilitate social interaction between the children themselves and their accompanying adults, and provide the opportunity for intergenerational knowledge sharing. For example, family visitors can talk about the game content while playing it, thus the exchange of information or experiences happens during the activity, not afterwards. The social aspects of playing can further contribute to visitor engagement within the museum (Horn et al., 2012).

Augmented reality

In exploring new pathways of interactive experiences for museum visitors, there has been a recent research interest in the emerging technology called augmented reality (AR). The following section provides a brief overview of AR and its application in a museum setting.

In brief, AR allows the user's perception of reality to be combined with digital content that appears to be part of the real world (Azuma, 1997). AR is the blending of the real and the virtual worlds in the user's perception. AR emerged as a defined concept around 25 years ago, when Professor Tom Caudell coined the term while working on a research and development project for Boeing (Feiner, 2002). The definition of AR has been evolving ever since. In the technology's early days, one of the pioneering AR researchers, Ronald Azuma, defined it as "3-D virtual objects […] integrated into a 3-D real environment in real time" (Azuma, 1997). This definition reflects how researchers at the time were concerned primarily with visual augmentation. Today, however, AR technology has advanced to be able to include the fusion of any digital media formats, such as video, text, audio, and haptic (touch). Thus, I find a more fitting definition is provided by Geroimenko (2012), who describes AR as "a real-time, device-mediated perception of a real-world environment that is closely or seamlessly integrated with computer-generated sensory objects" (p. 447). This technology attempts to bridge the gap between the virtual and the real world, blending the two environments into one in the user's perception. As shown in Figure 6, in contrast to virtual reality, where the user is immersed in a computer-generated vision and cannot see the real world, AR "supplements reality, rather than completely replacing it. Ideally, it would appear to the user that the virtual and real objects coexisted in the same space" (Azuma, 1997, p. 2).

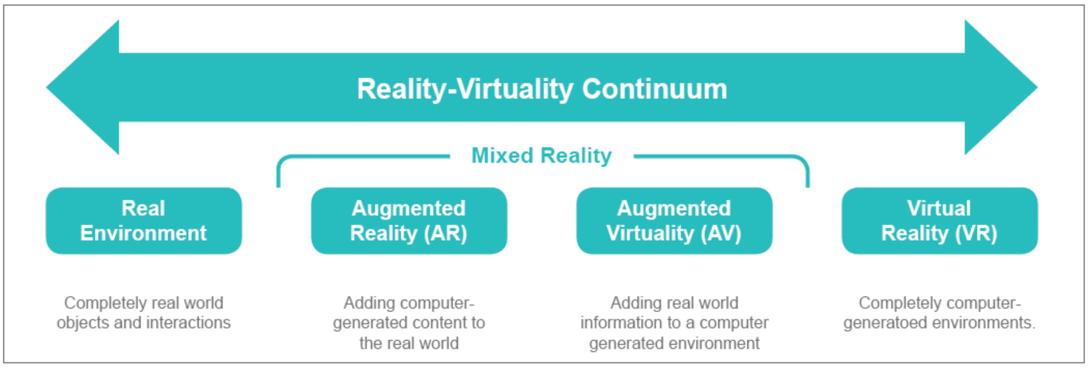

Figure 6. Reality-virtuality continuum.
Adapted from "A taxonomy of mixed reality visual displays", by P. Milgram, and F. Kishino, 1994, *IEICE TRANSACTIONS on Information and Systems, 77*(12), pp. 1321-1329.

Visually, AR applications take the view of the real world and overlay it with virtual content. As illustrated in Figure 7, the popular approaches to displaying *visually* augmented scenes to the viewer include: head-mounted devices (HDMs) such as see-through goggles; handheld displays such as smartphones or tablets; and spatial displays (Van Krevelen & Poelman, 2010). The last category includes screen-based displays such as computer monitors, and projection mapping, a technique that bends projected visual content around the surface of a real object (Jones, n.d.).

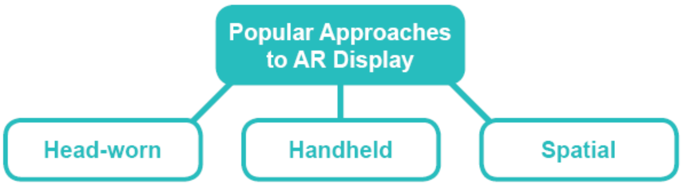

Figure 7. Popular approaches to AR display.

Due to the current popularity of smartphones and tablets equipped with sensors (such as camera or GPS) and internet connectivity required to display AR (FitzGerald et al., 2013), handheld displays present the most accessible option to the general public today, as users do not need to purchase additional devices such as HMDs to access AR content. Special AR applications such as Wikitude (Wikitude GmbH, 2015) and Layar (Layar B.V., 2015) can be installed directly on to users' personal devices. Also, according to Zhou, Duh, and Billinghurst (2008), handheld displays are an easy way to engage with AR applications in a public space, being "minimally intrusive, socially acceptable, readily available and highly mobile" (p. 198).

As a relatively new technology, AR has created possibilities for new types of experiences for museum visitors. Various forms of interactive AR guides have been explored by museums to deliver object-specific content to visitors (Damala, Cubaud, Bationo, Houlier, & Marchal, 2008), interactive installations where physical and digital content merges (Kondo et al., 2007), and educational games (Ciurea, Coseriu, & Tudorache, 2014; Thian, 2012). For example, the National Museum of Nature and Science in Tokyo, Japan, used handheld AR displays to allow visitors to augment skeletons of dinosaurs, visualising what they could look like and providing additional information (Kondo et al., 2007).

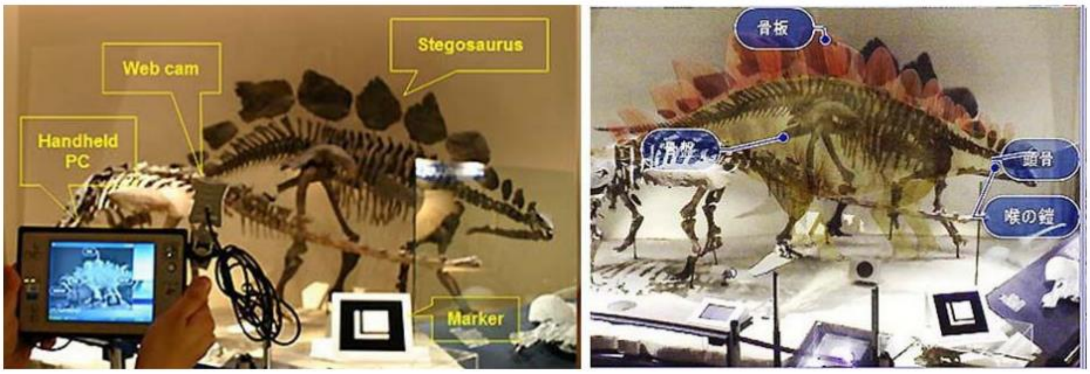

Figure 8. AR display at the National Museum of Nature and Science, Tokyo.
Left: the configuration of AR display. Right: AR content visible through the handheld device.
From "Mixed Reality Technology at a Natural History Museum" by Kondo et al., 2007.

Augmented reality games in museums

Several museums have implemented AR games into their exhibitions in an effort to enhance visitor experience, particularly catering for the younger generation. One example of a real-world application of AR game design in a museum is *A Gift for Athena,* developed by the British Museum and Samsung (Ciurea, Coseriu, & Tudorache, 2014). Using a tablet app, this project features a story puzzle game that sends children on a journey through the museum to find certain statues. The application rewards the players by providing information and further steps in the game (Ioannidis, Balet, & Pandermalis, 2014).

Furthermore, several formal evaluations of the potential of AR games in museums found that they are able to foster engagement and social interactions among visitors, and generally elicited positive responses from visitors. Some notable examples are described below.

For example, a game-based AR activity has been developed by the Asian Civilizations Museum in Singapore (Thian, 2012). In this game, players use their smartphones to bring terracotta warriors to life and play story-driven mini-games. The aim was to provide a compelling museum experience for young visitors such as children. Evaluation of player responses revealed that visitors felt that playing the game improved their museum visit experience. An important observation made by Thian (ibid.) was that a significant number of users (40 per cent) did not read the instructions, thus not getting the full experiences of the game.

Intrigue at the Museum is another example of an AR game for children aged 7-13 years (Rubino, Xhembulla, Martina, Bottino, & Malnati, 2013). The goal of the game is to identify a thief among several suspects by solving a variety of mini-games (quizzes and riddles) in order to obtain clues. The evaluation of the game indicated that it fostered engagement and social interaction among visitors, and evoked a high degree of satisfaction by young visitors. The authors suggest improvements could be made by adding a sharing option through social networks, and by giving the players a higher degree of control to create a more personalised experience.

Conclusion

To actively engage the visitors, museums must provide a range of experiences. In this chapter, I discussed the potential of game design and AR in creating interactive experiences for museum visitors. The key aspects of games that make them attractive for museum engagement are the increased intrinsic motivation and support of social interaction. The key aspects of AR are the novelty of blending physical and digital realities, as well as the ability to support social interaction. By uniting game design and AR, new kinds of interactive visitor experiences can be provided, involving real-life objects and the environment of the museum, with the ultimate aim of enriching the overall museum visit experience.

Chapter 4. Concept design process

Scrivener (2004) recommends that in a creative-production process, documentation should show how the researcher "arrived at, explored and expressed the identified issues, concerns and interests" (p. 3). This chapter documents the process of creating the concept of *ARticular*, and highlights some of the choices, concerns and challenges encountered. The process described herein focuses on the careful development of content and detailed design of the overall visitor experience with the game, not only the AR application design.

Key aesthetic considerations

From the review of contextual knowledge in Chapter 3, I outlined some key aesthetic considerations to address in my game design:

- Facilitation of physical/digital interactions using AR
- Facilitation of collaboration, communication between visitors
- Encouragement of creative exploration and experimentation.

Furthermore, from my interactions with the museum, I outlined the following requirements that relate specifically to the W&W gallery:

- Theme relevant to the W&W gallery: natural science
- Integration into the museum's W&W gallery space
- Intergenerational learning – child-adult knowledge sharing
- Consideration of visitor time constraints (game should not take too long)
- Appropriate for a target audience of 4 to 8 year olds.

The W&W gallery targets the children and family audience. Although the game is specifically designed for children aged 4 to 8, children will typically visit the gallery under adult supervision, whether it is their parents, grandparents or teachers (J. Hui, personal communication, October 10, 2014). Fostering forms of social interaction such as knowledge sharing, communication and collaboration engages both age groups in the activity. Furthermore, any potential learning benefits from playing the game can be encouraged by family participation. The Family Learning Project study by Borun, Chambers, Dritsas, and Johnson (1997) shows that designing museum exhibits with family learning in mind can significantly increase learning outcomes and behaviours.

Designing experiences for children

Before I could tackle the game design, I needed to have an idea about how to make the game appeal to my target audience. Designing for children was a new territory to me, as I had no previous experience in this area, therefore I referred to literature on child development to gain insight into designing age-appropriate activities.

As mentioned earlier, the game needed to appeal to a target audience of children aged 4 to 8. This age range covers both preschool and elementary school children, who are at different developmental stages of their life and thus require different approaches. Preschool children have a basic understanding of number, colours, size and time. As explained by Davies (2010):

> By age 4, preschool children can learn how to play simple board games. They can count, take turns, and understand that winning depends on reaching the last square first. However, preschool children do not enjoy structured games as much as fantasy play. Games with rules constrain their egocentric imagination, and they have not yet developed far enough cognitively to be intellectually interested in the structure and logic of a game. (p. 348)

As children get older, fantasy play is gradually replaced by activities that emphasise intellectual and physical abilities (Erikson, 1963). Davies (2010) describes ages 5 to 8 as a transitional phase in child development, during which children gain reasoning abilities and significantly improve their fine motor skills and hand-eye coordination. The development of new cognitive capabilities allows and motivates children to use logical reasoning instead of imaginative thinking. Davies (ibid.) argues that by the age of 6, children can engage in more complicated games such as ones requiring spatial orientation and visual organisation. Social interactions also become important at this stage, and children enjoy competing or collaborating with others.

As far as designing activities for children in general is concerned, a range of desirable aesthetic experiences is described by Mayesky (2002), with the key points summarised as follows:

- Sensual stimulation: providing children with materials that can be explored with different senses, such as sight, hearing and touch
- Interaction: designing activities that children can participate in, rather than observe, particularly with others
- Interest: choosing a theme that captures children’s attention
- Pace*:* ensuring the activity is not too fast or too slow, or too complex for children
- Reward: providing something worthwhile in the end.

In terms of designing play spaces for children, I found the general information provided by the New Zealand Ministry of Education (2015b) website helpful, as it summarises key considerations when designing environments for children. For example, it suggests not using too many bright colours to avoid overwhelming the children's senses, presenting play materials in an orderly way, and providing a variety of sensory experiences, including visual, aural, and tactile

Therefore, according to the aforementioned literature, to appeal to the target audience of 4 to 8 year old children, the game should ideally include elements of open-ended fantasy play for the younger children, and task-oriented problem-solving for the older children. It should provide a variety of sensual stimulation and the opportunity to play together with others.

Idea development

Through brainstorming and online research into interactive game design, I came up with the concept of an AR puzzle game about animal anatomy, inspired by classical board games, mix-and-match mobile games, and jigsaw skeleton games (for examples, see Figure 9). Using AR allows me to combine the physical interactions of classical board games with the aesthetic experiences of computer games, such as receiving a virtual reward.

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Figure 9. Examples of puzzle games for children.

It has been suggested that puzzles can enhance and promote cooperative play (Davis, 2012). Davis explains that in the course of completing a puzzle, together with either other children or adults, players will naturally share and support each other, whether by discussion about the placement of a particular puzzle piece or by jointly handling frustration at indecision, and then finally by sharing the joy of successfully finishing the puzzle.

Furthermore, puzzle play requires the player to problem-solve at a conceptual level (Kapp, 2012), through sorting, matching, recognising patterns and relationships, and working with numbers, shapes and space.

Overview of game design

Although game design is a highly complex process dealing with multiple considerations (Crawford, 1984), two common and important elements in any game design are known as the *mechanics* and the *aesthetics* of a game (Salen & Zimmerman, 2003; Schell, 2008). In this study, discussing the design of *ARticular* in terms of mechanics and aesthetics provides a frame of reference for commenting on the design process.

Game mechanics are the particular components and the workings of the game. They define the rules of the game, what objects are there, how things work and how players interact. Aesthetics are concerned with how the game "looks, sounds, smells, tastes, and feels" (Schell, 2008, p. 42). These features of the game aim to stimulate desirable emotional responses from the player. Hunicke, LeBlanc and Zubek (2004) have developed a vocabulary for describing common aesthetic experiences, shown below in Table 2.

Table 2

Common aesthetic goals in game design

Sensation	Game as sense-pleasure	**Fellowship**	Game as social framework
Fantasy	Game as make-believe	**Discovery**	Game as uncharted territory
Narrative	Game as drama	**Expression**	Game as self-discovery
Challenge	Game as obstacle course	**Submission**	Game as pastime

Note. Adapted from "MDA: A formal approach to game design and game research" by R. Hunicke, M. LeBlanc, and R. Zubek, 2004.

In terms of mechanics, the puzzle game involves two interaction modes: tangible interaction and device-based interaction. The tangible part of the game is to consist of puzzle blocks with sections of animal skeleton structures. These skeleton images are transformed by the AR application into virtual objects: firstly, 2D that show the relevant body part with flesh, and secondly, 3D animations that show the entire animal. One goal of the game is to reconstruct an animal skeleton by placing related blocks side by side. If the match is successful, the separate virtual 2D images are replaced by one 3D animated model showing the animal moving, followed by access to further content or features. Alternatively, players can design a mismatched fantasy creature. In such a case, there is no 3D object, nor further content, however, players can take a photo and send it to an email address. Some aspects of the game may be beyond the understanding of the younger children, particularly those below reading age. Consequently, a child would need an adult to support their play. Thus the game creates an opportunity for social interaction between children and adults.

While the game mechanics allow individual engagement by one player, the game is primarily aimed at facilitating multiplayer engagement, seeing as the social context of the W&W gallery is primarily family and school groups.

As shown in Figure 10, I explored the idea by making some sketches and gauging the puzzle form by mocking up a simple, rapid paper prototype from images found online. This provided me with a quick way to test and reflect on the tangible aspects of gameplay, before proceeding to the next step.

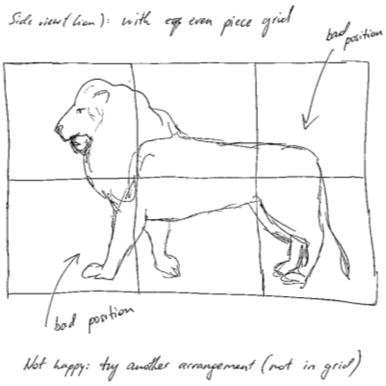

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Figure 10. Exploring the puzzle idea.

In terms of aesthetics, to facilitate both collaborative interaction and creative exploration, I decided to structure the game around two possible pathways of engagement: task-oriented and exploratory, which I labelled *construct* and *create*, respectively.

Construct (task): Players have to put together an anatomically correct skeleton of a particular animal. This means they have to sort through the many pieces laid out on the table to find the related ones. For successful completion, they receive a “reward” in the form of a 3D animation and access to more content (animal-related information).

Create (exploration): By joining together different blocks in different combinations, a player could create hundreds of unique “weird and wonderful” creatures, as shown in Figure 11.

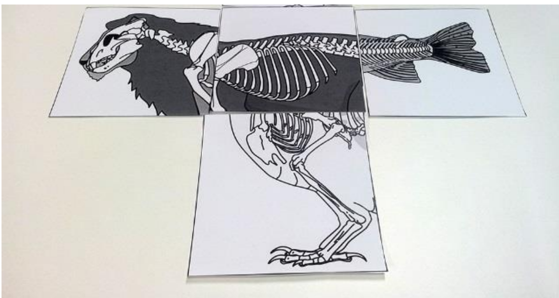

Figure 11. An example of a mismatched "weird and wonderful" creature.

By providing two possible pathways of engagement, children can potentially derive a range of aesthetic experiences from the game, including fantasy, exploration, challenge, and fellowship, as shown in Table 3. In doing so, I aim to provide intrinsic motivation for the players. This range also caters for the different skill levels appropriate for the developmental stages within the target age group of 4 to 8 year olds, with the hope of inducing a state of flow in the game, which is said to happen when the player's skills closely match the presented challenge, so that the player is neither bored by simplicity, nor frustrated by the difficulty (Kapp, 2012).

Although the game can be played as a task-oriented challenge of completing a puzzle, I decided not to include any point system or progress indication, nor a time score to limit gameplay, in order to keep the game open-ended. Incorporating an open-ended pathway into the game means there is essentially no failing or passing. In a museum setting, care must be taken to ensure visitors do not feel embarrassed in front of others by doing something incorrectly, as insecurity may lead to disengagement (Van Der Vaart, 2014).

Table 3

Possible aesthetic experiences in ARticular

<table>
<tr><th>Construct</th><th>Create</th></tr>
<tr><td colspan="2">Fellowship
Helping each other find new pieces to add, sharing the joy of 'winning', talking about the content</td></tr>
<tr><td colspan="2">Sensation
Touching the blocks and table, seeing the visual content, hearing the audio</td></tr>
<tr><td colspan="2">Discovery
Touching the blocks and table, seeing the visual content, hearing the audio</td></tr>
<tr><td colspan="2">Submission
The pleasure of playing the game as a pastime, with no specific goal</td></tr>
<tr><td>Challenge
Sorting and matching the pieces to complete an animal skeleton</td><td>Exploration
Sorting and matching the pieces to complete an animal skeleton</td></tr>
<tr><td></td><td>Fantasy
Creating fanstasy creatures, such as lion-fish</td></tr>
</table>

Selecting topic and content

I selected animal anatomy as the topic of the game. The primary reasons for choosing the animal topic were because animals are a popular subject for children, and because it is a suitable theme for the W&W gallery, where there is a multitude of preserved animals on display, including mammals, birds, fish and bugs (Appendix B). Thus, my game deals with a topic directly related to the museum artefacts within its vicinity: the anatomy of the animals exhibited in the gallery. Horn et. al (2012) argue that it is critical for games in museums to demonstrate some educational value to parents, so they are not disregarded as meaningless gimmicks, and suggest that this may be achieved by making the subject of the game relate to and expand on the museum objects within its environment.

One of my first tasks on this project was to determine what animals would be used in the game. The number of animals available in the game had to be small so as not to overwhelm the player with too many materials (Mayesky, 2002). I decided that it would be sufficient for the game to contain six animals, as this would provide enough variety. From the available animals, I selected widely-recognised animal species that often feature in children’s books, cartoons and toys, such as bear, lion, pig, fish[1] and owl. A bison was also included, as there is a large prominent skeleton of a bison at the gallery; I thought this would add more interest. Figure 12 shows the final selection of animals.

Figure 12. Final animal selection for *ARticular*.
Clockwise from top left: lion, sun bear, bison, fish (rainbow trout), snowy owl, wild pig.

[1] For the fish, I picked a trout, because it is a common type of fish in New Zealand (NIWA, n.d.).

For each animal, there would be a selection of relevant information within the application in the form of interesting facts, size chart, and photographs. I had to limit the amount of information available for each animal, to take into account the time constraints of a typical museum visit (Serrell, 1997). Nevertheless, with museums being places of informal learning opportunities, I see the addition of an educational aspect to the game as a way of increasing its value. Having textual content such as "fun facts" also means parents can read and interpret the text for pre-school children. This provides parents with a productive role to play in the activity: supporting children's learning at the museum (Tare, French, Frazier, Diamond, & Evans, 2011).

AR display approach

At this stage of the project, it became necessary for me to settle on an AR display approach that would suit the mechanics and aesthetics (Schell, 2008) of the game as it has been designed. As described in Chapter 3, at the time of writing this thesis there are currently three common approaches to AR display positioning: HMD, handheld, and spatial/projection (Van Krevelen & Poelman, 2010).

At first I considered displaying the AR content on a large projection screen in front of a traditional tabletop board game. However, studies suggest that an AR projection display used in this way can create an undesirable separation between the task space and the communication space in collaborative AR activities (Billinghurst, Belcher, Gupta, & Kiyokawa, 2003). In such settings, players would need to constantly shift focus between the screen, the board and each other, decreasing their awareness of each other's communication cues that are normally present in a face-to-face setting (Figure 13).

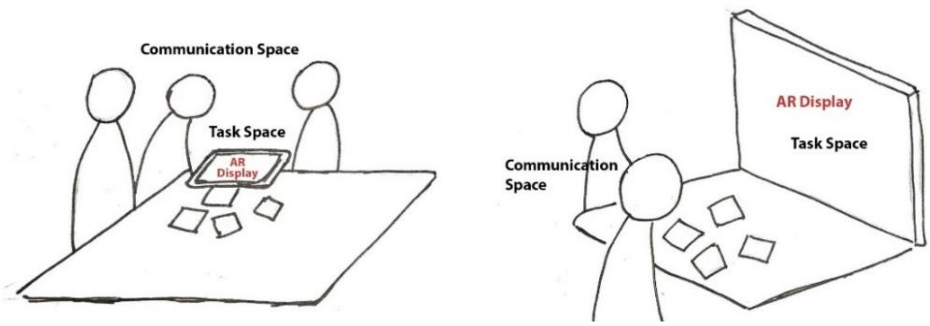

Figure 13. Difference between shared tabletop display and projection screen display.

In another study, Billinghurst, Kato, Kiyokawa, Belcher and Poupyrev (2002) compare the communication behaviours of subjects playing a collaborative puzzle game under three different conditions: with HMDs, with a projection screen, and face-to-face using real objects without AR. The authors find that "users felt they could pick up and move objects as easily in the AR condition as in the face-to-face condition and significantly easier than in the projection condition" (Billinghurst, Kato, Kiyokawa, Belcher & Poupyrev, 2002, p. 69). On the other hand, the experiments also found that "using a HMD to show AR content made many users feel distanced from their collaborator and severely reduced their perceptual cues" (p. 120). The authors suggest that using handheld AR displays instead of HMDs may actually restore some of the lost communication cues, as a small and unobtrusive handheld display means that users can see each other over the top of the display, as well as the AR content on the display.

Due to the aforementioned considerations, I decided to use a handheld, screen-based AR display in the form of an Apple iPad. The iPad is a portable handheld touchscreen device capable of supporting AR applications (Carmigniani & Furht, 2011). As the iPad is a well-known consumer product, my assumption is that this would make it less intimidating for users to approach than a special, previously unknown device. However, after reflecting on this decision, I realised it may be awkward and difficult for players to simultaneously hold the iPad and manipulate physical objects, as well as interact with the touchscreen, especially for children who are still developing their fine motor skills. In fact, such complexity may prove to be more suitable for an octopus (Figure 14).

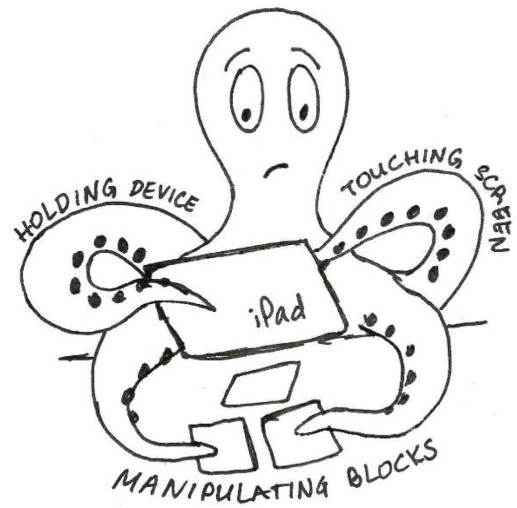

Figure 14. The challenge presented by using a handheld iPad for *ARticular*.

I decided that it would be sensible to challenge the players to do only two things at once, for example, "handle blocks and touch screen" or "hold device and touch screen". To free up players' hands while constructing or creating animals, the tablet would be need to be mounted on a special stand, so that blocks may be placed underneath it. Players would still be able to lift the iPad from the stand when required, for example, to view the 3D object from different angles. Additional advantages of this approach include the following factors:

- AR content is not visible until the block is in front of the device's camera, creating intrigue around the as of yet unseen objects that children can discover
- There is a combination of physical and digital interactions (manipulating tangible blocks as well as interacting with the touchscreen device)
- iPad tablets are readily available – no need to develop new, expensive technology
- The virtual content can be packaged into a downloadable, updatable application.

In the case of *ARticular*, the mounted iPad tablet effectively becomes an interactive tabletop screen that supports multitouch interaction. Studies on interactive tabletops show that they are a useful tool in enhancing collaborative learning (Villanosa, Block, Hosford, Horn, Shen, 2014). By allowing simultaneous input from multiple users, tabletop device surfaces enable users to interact with each other in a face-to-face way, and to be more aware of each other's actions, thus supporting collaborative engagement and providing incentive for player interaction (Rick, Marshall, & Yuill, 2011).

Furthermore, a study conducted at the Harvard Museum of Natural History suggests that interactive touchscreen tabletop games have high potential for museum learning and collaboration (Horn et al., 2012). The study presented the design and evaluation of a tabletop game where players construct evolutionary trees by dragging icons of different species on the screen. The results show that players were collaboratively engaged in focused, on-topic interaction with the exhibit for prolonged periods of time (ibid.). As stated by Horn in an interview (Sherman, 2012), "not only are tabletop games motivational, but they also cue social practices of game play that spark productive collaboration."

Figure 15. Sketch of proposed AR station setup.

While my game design does not involve a large interactive tabletop as such, it utilises an iPad tablet mounted on a table, which bears similarity to an interactive tabletop. In many ways, it is a viable low cost solution. This set-up still allows for multiuser, multitouch input and face-to-face interaction, as players gather around the iPad.

However, studies show that in comparison with the larger multitouch surfaces, the multitouch collaboration potential of the iPad tablet is not fully realised due to its relatively small screen size. Henderson and Yeow (2012) report that when iPad tablets were tested in primary schools, the teachers observed that while multiple students can gather around to view the display, only one user usually operates it. In the case of *ARticular*, this is not an issue of primary concern, because the gameplay is based primarily on tangible block manipulation, and digital interactions are minimal.

Nevertheless, it was decided to supplement the museum-based shared tablet version with a personal smartphone version in the form of an app that visitors can download (Figure 16). This means that museum visitors can also play *ARticular* using their own smartphone device. Having additional AR displays, such as smartphone, to view the AR contents also means that children can work in parallel, not having to wait to take turns at a single iPad. For convenience, the concept design presented in this study is developed for Apple iPhone, though ideally the app would be available on Apple, Android and Windows platforms, and support multiple versions.

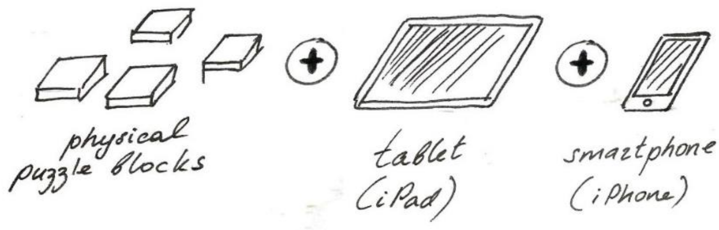

Figure 16. Sketch of tangible/digital tools for playing *ARticular* at the museum.

Finally, it allows visitors to take the game home with them if they wish; a set of puzzle blocks could be purchased from the museum shop, or they could simply download and print the skeleton images at home to make puzzle pieces recognisable to the software. This provides an opportunity to extend visitor engagement beyond the walls of the museum, as visitors take part of the experience into their homes or into their schools.

Technical feasibility testing

It was important to ascertain the technical feasibility of the idea in terms of AR functionality. While technical development of a prototype is outside the scope of this study, I still wanted to ground my design in actual technology available at the time of writing this thesis. For AR functionality, this involved two experiments: first, testing the recognition and detection (known as tracking) quality of my skeleton images, and second, determining how to replace the separate 2D images that are superimposed on top of physical puzzle blocks with a single 3D object once a certain block arrangement is made (such as a full lion skeleton). I decided to develop a small prototype to conduct these tests. After some research, Vuforia *and* Unity platforms were selected for as the AR development tools for *ARticular*. Vuforia is a software that enables the display of AR content on a device's screen, using the capabilities of the device's camera to track objects in real time, overlaying them with AR contents. Unity is a game development software that allows the programming of 2D, 3D images, animations and special effects. These two platforms can be configured to work together to create AR content for devices such as tablets and smartphones.

I was able to do the first part of Vuforia testing myself, which involved augmenting some generic skeleton images sourced on the internet with 2D AR images and some of my draft artwork designs. Through these trials I found out that tracking is better if the tracked images, called "targets", contain rich visual detail (Figure 17). This informed my future artwork development.

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Figure 17. Image augmentability (tracking) feedback in Vuforia.

The second part of AR testing was more advanced, as it involved the following scenario: when certain targets are put together in a particular order, their corresponding 2D AR images are replaced by a new 3D object. For example, if a player assembles a lion out of the skeleton blocks, the separate animal body part images shown on screen are replaced by a 3D animation of a roaring lion. If any of these blocks is then removed or obscured from the camera view, the 3D object is replaced again by the separate 2D images. As I tried to work it out myself, it became evident that this level of programming complexity was beyond my own technical skill, and that this part required the assistance of a skilled game developer.

Seeking a solution, I explained my idea to a member of my expert reference group who specialises in computer game development. This individual was able to develop a solution in Unity and Vuforia that confirmed the technical feasibility of the concept, as shown in Figure 18. The dialogue with the game developer also provided me with valuable insight and the opportunity to see things from different perspectives, leading to new concerns or ideas, for example, considering the proximity and precision of the block arrangement needed to trigger the 3D animation. I realised that it would be appropriate to allow for a degree of flexibility, as the younger children in the target audience are still developing their fine motor skills, which can affect the precision of the object placement (Marco, Cerezo, Baldasarri, Mazzone, & Read, 2009). This was taken into account when designing the dimensions of the sensitive areas around the blocks in Unity: the area was increased to allow for more leeway. However, the sensitivity allowance of the arrangement would ideally be user-tested.

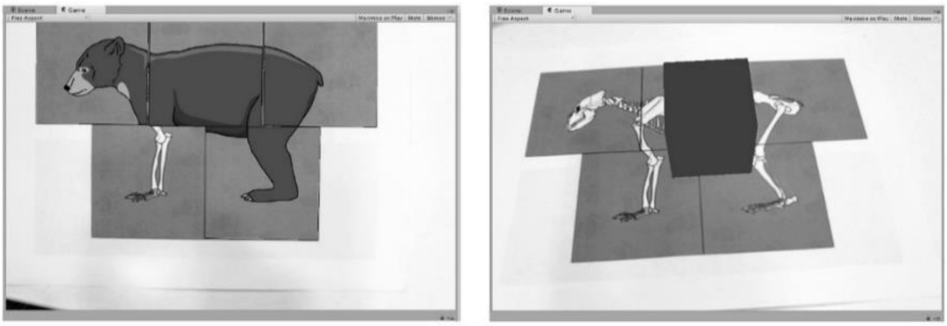


Figure 18. Developing AR functionality in Vuforia.
Replacing multiple 2D images (left) with a single 3D object (right)[2].

Further down the track, I conducted another test in Vuforia and Unity to investigate how the application can support the display of more than one completed animal skeleton on screen, should the player decide to construct more than one. Appendix K shows a screenshot of Unity displaying two completed animal skeletons with their corresponding 3D objects, thus proving it is technically possible.

[2] The image on the right shows a cube as a placeholder for a 3D animal model, as no appropriate model was available at the time of testing.

Artwork design

When working out the number of the puzzle pieces, my goals included keeping the game simple so as not to overload the player with too many pieces to find, not making the game too time consuming given the limited duration of a typical museum visit (Serrell, 1997), and not hindering AR performance, as having too many tracking targets for each animal could affect the tracking efficiency of the app. The content selection contained six animals. If each animal was to be divided into 3 to 5 parts, there would be a total of 18 to 30 puzzle pieces in a set. This number of puzzle blocks provides variety, particularly if several players play together.

My next design challenge was to design skeleton illustrations in such a way that they could be split into 3 to 5 parts each, while allowing the interchanging of different body parts across animals, such as attaching a lion's head to a bear's body, as this would be needed for the "*create*" game pathway (p. 22) to allow children to design a "weird and wonderful" creature. Reflective practice was useful in working out this design challenge, taking me through artwork design iterations until a suitable result was reached (see Appendix J for an example of reflection-on-action episodes).

Eventually, I achieved a solution by having all the animals facing the same way and being of similar size (Figure 19). At first, I thought such unrealistic scaling may be an issue, but after carrying out some further visual research (Appendix N) into children's puzzle games, I found that most of them did not have realistic representations of scale. Therefore, I decided that the animal images would not be to scale. Consequently, I considered adding a size comparison chart to the application's animal information section, but found that this was complicating the design; therefore I decided to not necessary to include such a chart.

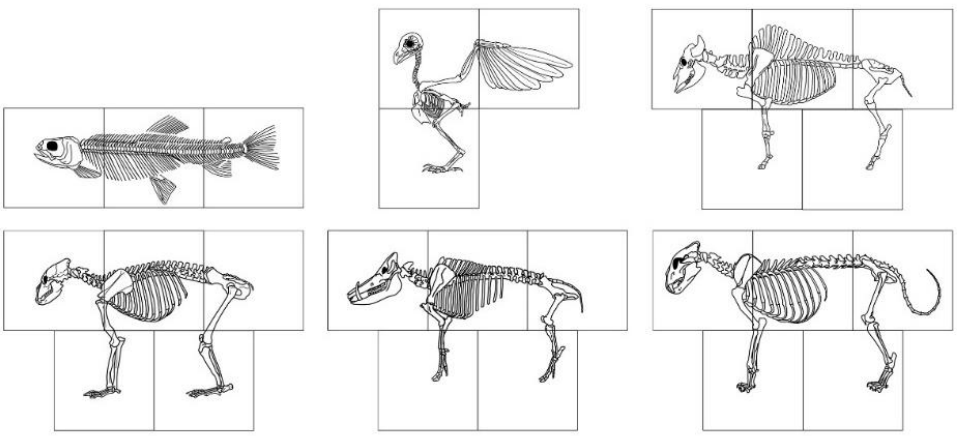


Figure 19. Skeleton structure on puzzle blocks.
Clockwise from top left: fish, owl, bison, lion, pig, and bear.
Note: My skeleton artwork was adapted from anatomical drawings shown in Appendix C.

Artwork design for the skeleton images, as well as their corresponding 2D body images, was also closely tied with the technological capabilities of Vuforia, as I had to ensure that the images would be tracked efficiently in AR view. In Vuforia, each target image is given an augmentability rating out of 5, based on the amount of detail in the image which aids detection and tracking. A low rating means that the image would be difficult to track. My initial design of the skeleton artwork was not particularly rich in detail, as it was stylised as simple, clean black and white line art, without gradation in shading (Figure 19, page 31).

Furthermore, the way the skeleton structures were distributed over the puzzle blocks meant that some blocks would contain only a small part of the image, such as the tail bones, with a large amount of empty space. From earlier experiments in Vuforia (Figure 17, page 29), I knew that such images would have poor tracking. In order to keep my artwork styling, but improve the overall augmentability rating of my artwork, I experimented with adding a background image to the blocks that would increase overall detail on the target images. In Vuforia, colour is not recognised, therefore adding a solid background colour would not provide a solution. What Vuforia does recognise, however, is contrast and sharp, edgy details in the image, referred to as "features" (Qualcomm Vuforia Developer Portal, n.d.). After some experimentation with various background image options, improved augmentability rating was achieved by the addition of a background pattern, as shown in Figure 20. Although the Vuforia website does not recommend using repetitive patterns to improve the augmentability rating, I found that in the case of my artwork, there was evidence of improvement.

Figure 20. Screenshot: improved augmentability rating in Vuforia.

The background pattern design is unique for each animal, consisting of a relevant image, such as paw prints for the lion, fish scales for the trout, feathers for the owl, and hoof prints for the pig. This additional visual layer offers a hint for matching related blocks, as well as contributing to the educational content of the game. For instance, children see what a bear paw print looks like, and can analyse how it is different to a lion's print (Figure 21). Adults can then explain to children why it is different, engaging in parent-child communication and knowledge sharing.

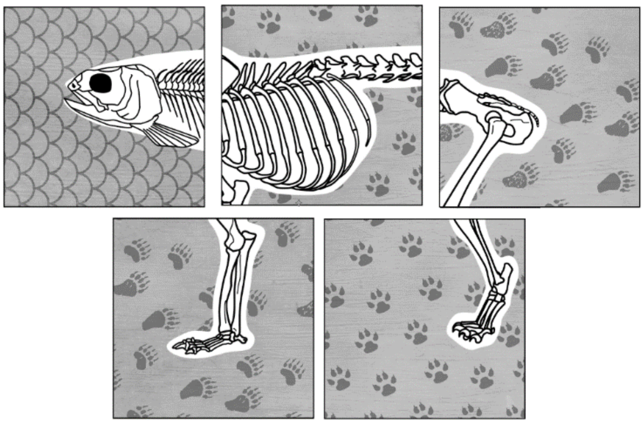


Figure 21. Comparing different background patterns.

Once I finished the illustrations, another round of reflection highlighted further areas of improvement, as discussed below.

Changing the owl wing: When I originally designed the owl skeleton, the block containing the wing was nearly empty, because of the small amount of bone structure it contained. I decided to give it more detail and make it look like a wing adding the outline of large feathers to it, as shown in Figure 22. After further reflection, I made the feather outline lighter in colour and dashed, to differentiate it from the bone outline.

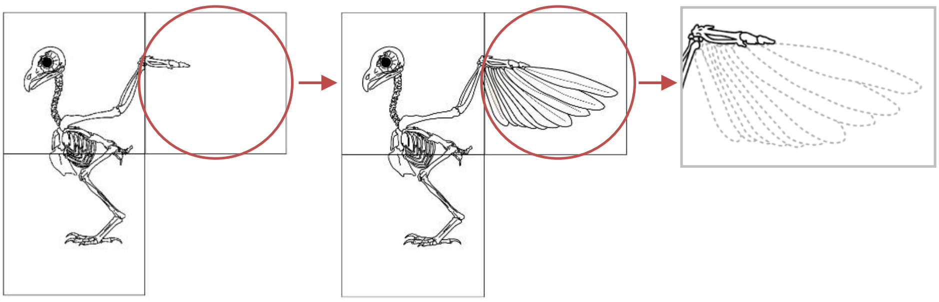


Figure 22. Diagram of the owl skeleton distributed across blocks.
Original design (left) and improved design (right).

Changing the bison head: Originally I had the bison skeleton structure distributed over the blocks in a different way to the other three mammals (lion, pig, and bear), because the bison skeleton illustration I made had a "droopy head" that did not fit into the other temple. However, after playtesting the pieces myself, I became aware that this may cause confusion to players, if they try to align the bison's body pieces the same way as the other mammals and find that it doesn't work. Therefore, I modified the illustration to raise the head up to fit the standard template used for other mammals (Figure 23).

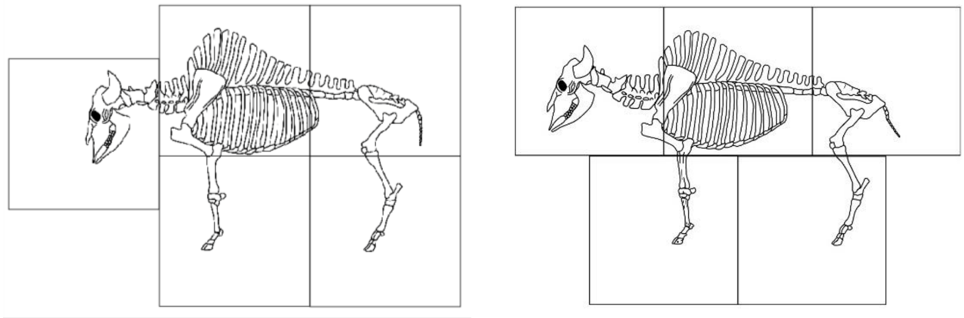


Figure 23. Bison puzzle blocks.
Original design (left) and improved design (right).

The physical aspect of block design itself had several considerations. Safety was one consideration: ensuring that the puzzle blocks are not too small, to avoid choking by toddlers who may come across them in the gallery, or too sharp, to avoid injury. Keeping this in mind, I designed the blocks to be 77mm^2 with a 15mm thickness, thus being large and thick enough to be easily grasped, and made of wood, with the edges slightly rounded. The textured, tactile nature of the wood surface invites touching and grasping, and is relevant to the natural science theme of the gallery. At first, I envisioned the artwork to be printed on to the block's flat surface. However, after a discussion with the museum professionals from my expert reference group, it became evident that such a two-dimensional image provides a limited entertainment value, and puzzle pieces with sculpted or relief features may be more interesting. Consequently, I redesigned the outline of the skeleton to be slightly raised (for example, by wood relief carving), thus also providing additional tactile sensory stimulation. Figure 24 shows a sketch of a block.

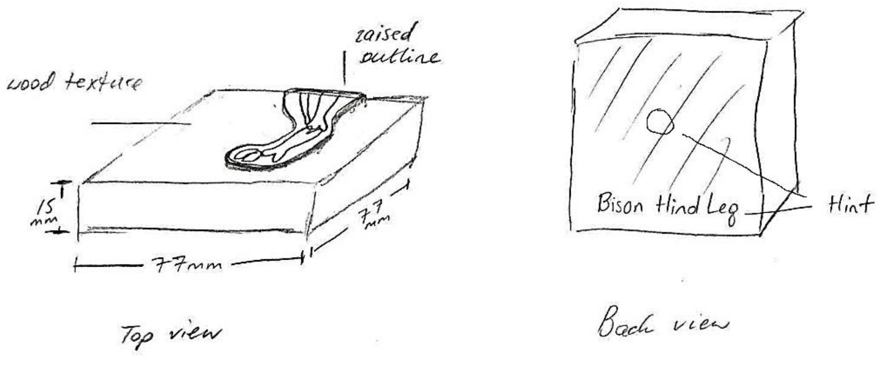


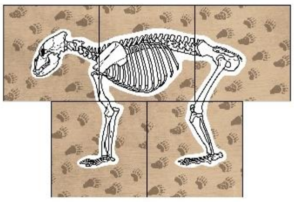
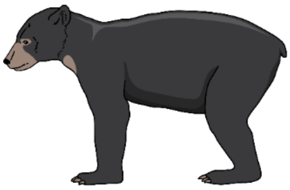
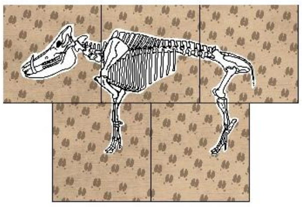
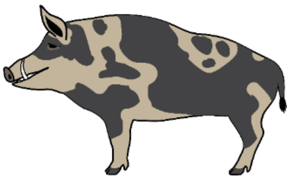
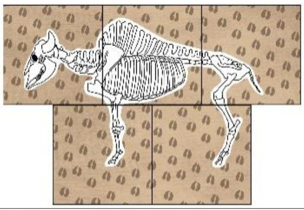
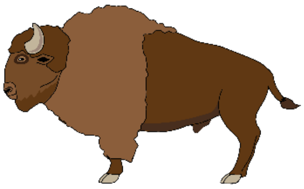
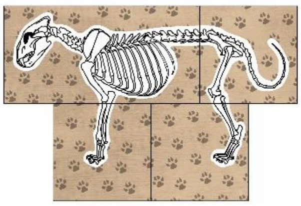
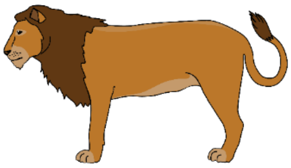
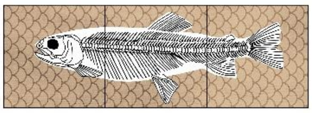
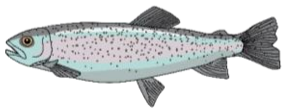
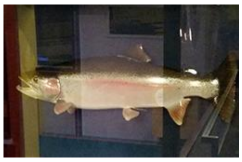
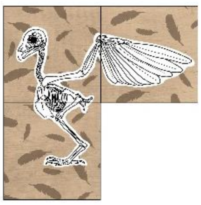
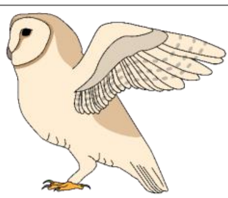
Figure 24. Sketch of the puzzle block design.

AR artwork

Having designed the skeleton artwork, I moved on to illustrate the physical bodies of the animals to be shown in AR view. Again, the stylistic approach was simple, clean, and cartoonish; I sought advice from a member of my expert reference group who is a children's illustrator (S. Amelina, personal communication, July 2014). As shown in Table 4 below, the animal illustrations correspond with the existing animal exhibits in the W&W gallery, so that players can attempt to find the animals after playing the game.

Table 4

ARticular *animal artwork*

Skeleton and Background	2D AR Image	Exhibit
		
		
		
		
		
		

The animal body artwork is designed in Adobe Illustrator to precisely overlay the skeleton image, as visualised in Figure 25. Each body part is stored as a PNG file with a transparent background so that the block texture can still be visible underneath it.

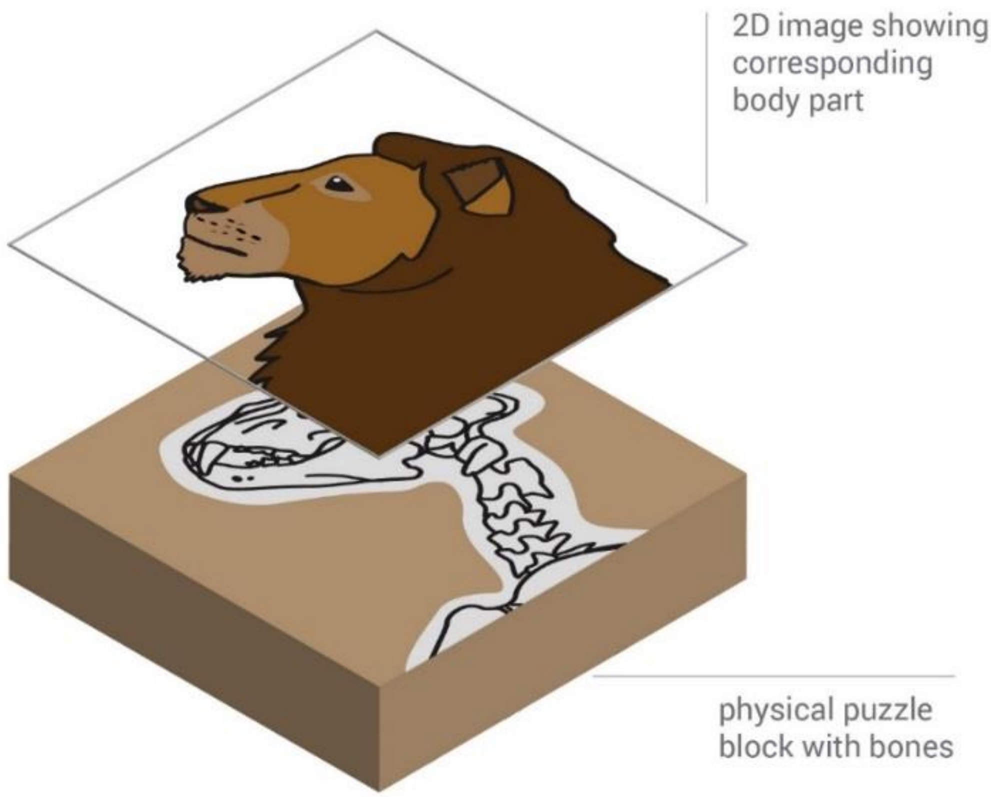


Figure 25. Illustration of the 2D AR layer placement over the puzzle block image.

The 3D object replaces the separate 2D animal body part images on screen if the puzzle blocks are assembled into the proper shape of a particular animal. (Note: if the player chooses to create a mismatched "weird and wonderful" creature, only the 2D images would be displayed; no 3D content would be displayed, because the system cannot know when the arrangement is finished). The 3D model provides a reward intended to increase motivation and engagement (entertainment value), and attempts to add to the educational value of the game by showing children how this animal moves. At the same time, children do not need to know exactly what outcome they will achieve until they construct an animal skeleton, as uncertain rewards are more motivating (Schell, 2008).

The size of the 3D animal model is roughly the same as the skeleton size, so that it fits within the frame of the device screen, allowing users can take a photo of it (Figure 26).

Figure 26. Computer-generated mock-up showing a 3D lion.
(Right to use third-party 3D lion model shown in Appendix U).

The New Zealand Ministry of Education website states that "Children need to be presented with a diverse range of styles and images that challenge children to think about different ways subjects can be portrayed" (Ministry of Education, 2015b). In my game design, children are presented with a range of depiction styles for each animal species: outlines, colourful cartoon drawings, 3D models, and photographs.

Name and logo

My next creative challenge was to come up with a name for the game. I wanted it to have "AR" somewhere in the title to indicate that it is an augmented reality game. The capitalisation of the first two letters in the name indicates that this is a project concerning augmented reality, abbreviated as AR.

Through brainstorming, I came up with the names *ARticulate* and *ARticular*. The verb articulate means to unite something by a joint (Articulate, n.d.), and the adjective articular means "of or relating to a joint" (Articular, n.d.). In anatomy, a joint is the location at which bones connect (Joint, n.d.). This seemed appropriate, as within the game the user needs to connect bones to form a skeleton. Initially, the variant *ARticulate* was considered, and I developed a few quick drafts of it as a logotype. My initial logotype designs had a very clean and formal look, a style I came to use almost habitually after years of designing corporate logotypes (Appendix D). However, after reviewing my logo drafts, I realised that this choice may be misleading, as the word articulate is commonly associated with language, not joints. The formal look of the typeface also did not seem appropriate for a children's game. Thus, a decision was made to use the word articular instead, and the logotype design was styled in a quirky, uneven typeface to reflect the nature of the game (Figure 27).

Figure 27. Draft of the typographical styling of the name.

Because the game is developed as an app, it needed a supporting image to be used as an app icon. I decided to develop a skeleton-themed logotype to reflect the game's subject. One of the animals included in the game was a bison, and I found its skull to be visually more distinct and recognisable, in comparison to the other animals' skulls, due to its prominent horns. Thus I decided to make it into a logo.

Using Pinterest, an online visual bookmarking tool, I accumulated a collection of bison, bull and cow skull images for visual reference, as well as a collection of general cartoonish artwork styles for stylistic inspiration. From these resources, I developed the logo concept for *ARticular*. Figure 28 shows the design process leading to final logo design, before any colour or texture was applied to it.

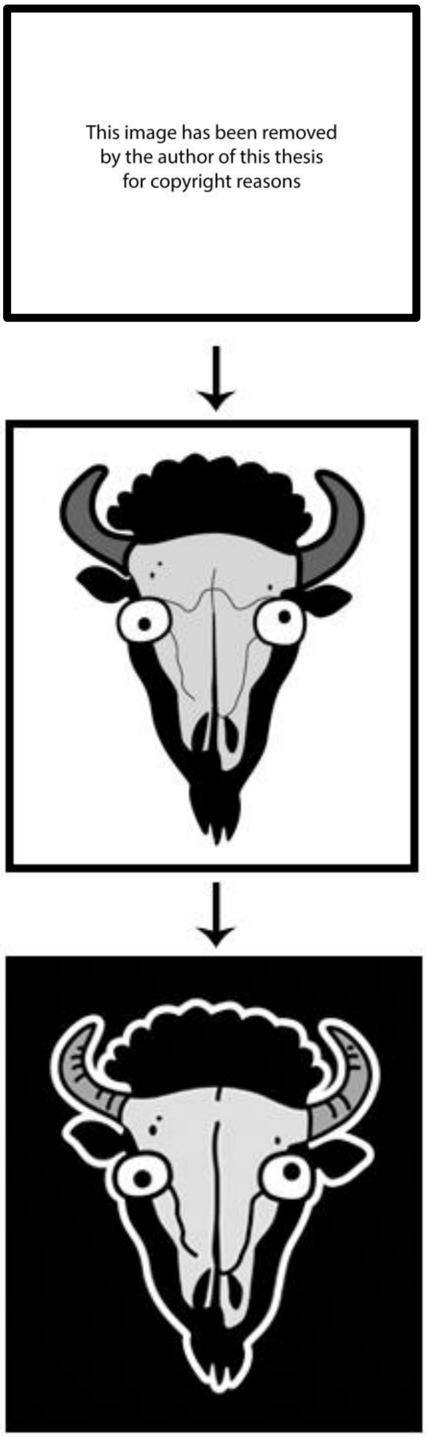


Figure 28. Logotype icon design.
From top: Visual research and inspiration, initial vector illustration,
final vector illustration (black and white).

Museum space configuration

Choosing a space

Encouraging children to engage in an activity involves providing an environment that offers interesting play materials and enough room for them to explore and to try things out. When it comes creating a designated area for puzzle games, the New Zealand Ministry of Education website (Ministry of Education, 2015a) provides the following guidelines:

- Provide a quiet, comfortable environment where children feel unhurried
- Most children like to work on the floor or at a low table
- Display puzzles in an orderly way and within easy reach of the children

As a puzzle game with a number of tangible parts, *ARticular* needs to occupy some physical space. Because the game was developed with a particular museum environment in mind (W&W gallery), my design has to work within the constraints and features of the gallery's interior. There were several areas within the W&W gallery I considered as potential sites for the integration of *ARticular* (Appendix E), ultimately choosing a low table in a well-lit, spacious area of the gallery, as shown in Figure 29.

Figure 29. Low table at the gallery.
The potential site for integration of *ARticular* within the W&W gallery.

This area provides a unique physical space for *ARticular* – the playground. The large, low table can accommodate multiple players gathered around it. Designing a game around a shared space, such as a table, promotes physical closeness between players that allows them to coordinate their efforts efficiently to complete tasks (Rick, Marshall, & Yuill, 2011). As identified by Borun and Dritsas (1997), providing physical access from multiple sides for multiple users, including both children and adults, is a key factor in successful family-oriented museum exhibits. However, I noticed there were no chairs around the table, which may make it uncomfortable for adults, particularly elderly grandparents accompanying children at the gallery. To rectify this, in my concept I propose adding several low stools that can be tucked away under the table when not in use (Figure 30).

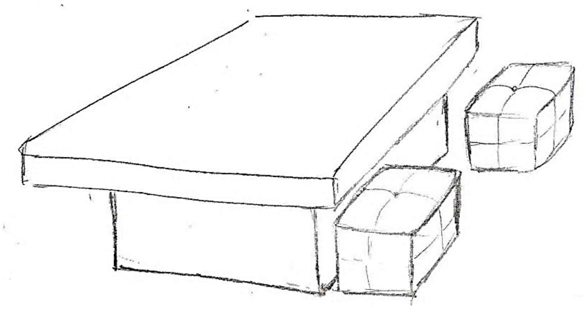


Figure 30. Sketch illustrating the addition of low stools to play area.

Putting the game on display

The New Zealand Ministry of Education website advises that play materials should be well displayed in “an orderly and considered way” (Ministry of Education, 2015b). I needed to think of a way to attractively display the AR game, rather than just scattering the blocks on the table. Furthermore, I realised the area should contain printed information signs about the game, as visitors may be reluctant to approach the iPad tablet if they do not know what to expect from it. For example, in the European MeSch project (Van Der Vaart, 2014), the Allard Pierson Museum tested the usability of iPads containing an AR application on museum visitors. They found that many visitors were reluctant to engage with the iPads, possibly due to a confusing interface and the visitors’ general unfamiliarity with AR technology (para 3).

To create a well-defined display area for *ARticular*, I conceived of a table mat design, similar to the table mat used in the existing AR station in the W&W gallery (Appendix A). The table mat for *ARticular* needed to be large enough to accommodate the iPad, a designated area for puzzle assembly, instructions explaining what to do, branding, and room for other blocks. Figure 31 shows an example of a drafts leading to a paper mock-up created as part of the iterative process of the design of the table mat.

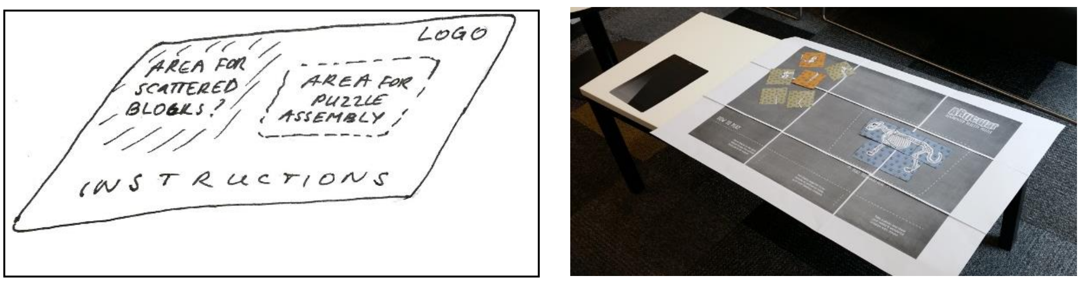


Figure 31. Sketch leading to a paper mock-up of the table mat.

I felt that displaying printed instructions from the start was important, considering that many visitors will have no previous AR experience, as AR is not yet widely adopted in the consumer technology market. Having illustrated step-by-step instructions printed on the mat allows visitors to see what they can do from the start. In the case of the aforementioned Allard Pierson Museum study, visitors found it difficult to understand how to use the iPad to view augmented reality content (Van Der Vaart, 2014). Letting visitors know what to expect may also contribute to removing some of the psychological barriers between a novice user and the technology.

Once I had determined the approximate layout of the table mat, I worked on refining the artwork, creating a look that is consistent with the UI design of the application. Here, however, I encountered indecision in terms of the colour scheme (Appendix M). The blue-coloured background I initially chose looked too overwhelming to my senses. I decided to change it to a natural wood colour, which was easier on the eyes and still worked with the colour scheme of the design.

Figure 32 shows further changes made to the table mat design, such as adding another step to instructions to emphasise the *create* pathway (making a fantasy creature), as well as adding a QR code that allows visitors to download the app on to their personal devices.

Figure 32. Revised table mat design with new additions.

I viewed the full-scale design through an iPad camera to get an indication of the suitable position of the iPad stand in relation to the table mat and the placeholder for the designated puzzle area (Figure 33). Although there is no limit to the number of blocks that can be placed in the AR view, due to the small size of the iPad screen and the camera distance in its fixed (mounted) position, the puzzle area indicated on the table mat is designed to contain up to six blocks at a time.

Figure 33. Testing table mat design with iPad.
Note. In the photograph above, iPad screen is showing standard camera view, not AR overlay.

The table configuration features two tablets; one tablet on either side of the table. The tablets would be mounted on stands fixed to the table, but able to be lifted, if the player wished to look at the AR objects from a different angle or to take a close-up photo. The puzzle pieces can be stored away in a special container, as illustrated in Figure 34. For sketches of possible container design variations, see Appendix F.

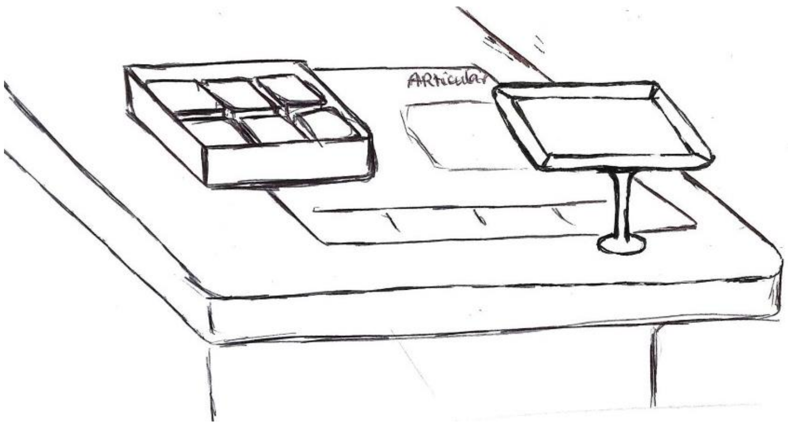


Figure 34. Sketch of *ARticular* table configuration.

User experience design

One of the biggest challenges in my design process was deciding what steps, features, and functionality to include in the application design of *ARticular*, as they would affect the kind of user experience the game could offer to the player.

According to Rogers, Sharp, and Preece (2002), user experience is concerned with how people feel about using a product, and is a fundamental part of interaction design. The goal of user experience design is to create products that are easy and aesthetically pleasing to use for their target audience (Norman, 2004). Aspects of user experience design involve the features and functionality of a product, and the way it looks and feels. The latter is usually referred to as user interface design, which is described further in the next section.

In designing AR user experiences, where applicable, Dünser, Grasset, Seichter, and Billinghurst (2007) suggest using several well-known user-centred design principles borrowed from the general field of HCI design, as few AR-specific guidelines have been developed to date. As not all of their recommended principles were applicable in my game design, I will discuss the key guidelines that were considered in the creation of *ARticular*. These principles include: affordance, reducing cognitive overhead, and learnability.

According to Norman (1988), affordance refers to the "perceived and actual properties of the thing, primarily those fundamental properties that determine just how the thing could possibly be used" (p. 9). In the case of *ARticular*, the physical blocks afford being handled, sorted and matched, while the tablet interface has the affordance of being touched.

Reducing cognitive overhead is concerned with minimising the amount of effort needed for the user to interact with the interface itself, so that the user can focus on the task better. Cognitive overhead is described by Rizzo et al. (2005) as "the extra non-automatic cognitive effort required to interact/navigate" (p. 1). In the design of *ARticular*, this meant striving to keep the interface simple and easy to navigate, so that the players can focus on arranging the puzzle blocks. Initially, for example, I considered adding a timer to the museum tablet interface (Appendix L), but rejected this idea as it could be distracting for the player. Thoughtful visual design can contribute to reducing cognitive overhead (Kirsh, 2005), and this topic is addressed further in this section.

Learnability means the user is able to learn how to use the application easily. However, as *ARticular* utilises a blend of physical and digital interfaces unique to AR, which museum visitors may not have experienced yet, the possibilities need to be explained before the users can play the game efficiently. Thus I decided to provide a brief set of simple, succinct “how to play” instructions that appear on screen every time a new game is launched. Experienced users can skip instructions.

To visualise the potential experience of the visitor, I conducted a mental rehearsal, described as follows. The visitor approaches the game. When not in use, the iPad screen displays a “Touch screen to begin” message. The player taps the screen which prompts “how to play” instructions with illustrations (three steps maximum). The player takes one block and holds it under the iPad, seeing the AR 2D image overlay onscreen. The player now decides to either find the rest of the animal amongst the pieces (*construct* pathway), or to explore what happens with random pieces (*create*). The player manipulates the blocks with hands under the iPad screen. If he or she constructs an animal skeleton, the device displays a 3D animated model of the animal. After a few seconds, or if the player taps the 3D model first, a pop-up message appears offering the player to “learn more”. The camera button is also present on screen throughout the game, allowing the player to take a photo at any stage. If the player takes a photo, he or she is then prompted to send the photo together with animal information to an email address. If the player selects “learn more”, the display presents additional information about the animal, followed by a message challenging the player to find the animal in the gallery. The interface restarts back to the first screen so a new game can begin.

To highlight the key steps I needed to address in my UI design, I sketched a simple flowchart as shown below in Figure 35.

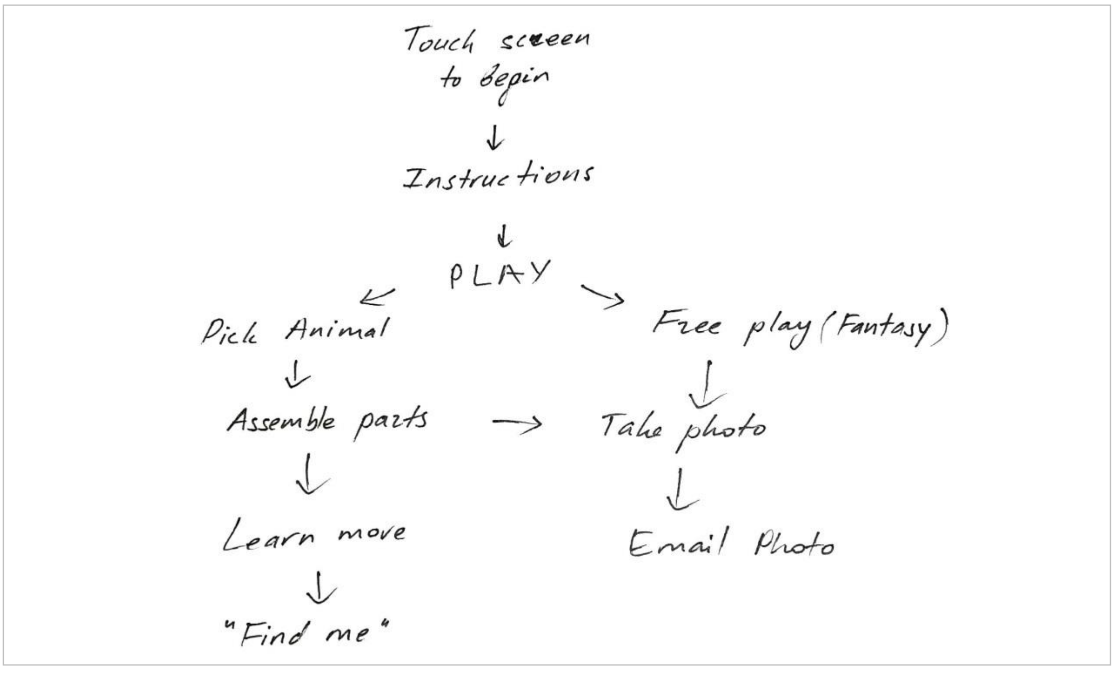


Figure 35. Sketch of the game flowchart for museum tablet.

From this flowchart, I drafted a storyboard of the user experiences in the museum, shown in Appendix O. Discussions of the user experience with the museum experts (Pokel & Hui, personal communication, January 29, 2015) highlighted the need for players to be aware from the start of what animals are available, so that they can set themselves a task of finding a particular animal. Also it was noticed that the tablet concept did not feature any sound effects at this point, but that audio would be a desirable addition as it helps to provide additional sensory stimulation.

At first I considered incorporating these suggestions into my design by means of adding a new step to the tablet UX in the form of a visual chart of animals at the start of the game, and adding animal sounds to each image when the user taps on it. However, there is research suggesting that when visitors encounter a familiar piece of technology (such as the iPad) in the museum, they try to use it in the way they would normally use it outside of the museum space (Van Der Vaart, 2014). In the case of the AR iPad usability study at the Allard Pierson Museum, visitors often attempted to tap images on the screen that looked like icons (ibid.). Therefore, after careful consideration I decided not to include such a “menu” to the iPad interface, lest it misleads the players into believing they are limited in what animals they can create once they have touched an option. Instead, perhaps the selection of animals could be placed on the table as printed cards showing full body images, or depicted on the side of the container. Therefore, I took this step out of the user journey, as shown in Appendix O.

As for exiting the game or starting over, Horn et al. (2012) provide the following suggestions for entry and exit into museum-based interactive activities:

> …there should be easy and obvious ways for visitors to start the game over from the beginning. The trick is make sure that this mechanism is not too easy to trigger in order to avoid individual visitors accidentally (or even intentionally) restarting the game while other people are playing. Finally, as is common practice with many interactive exhibits, games should have a built-in timeout that automatically restarts the activity after around 30 seconds of non-use. (p. 8)

In *ARticular*, once players have successfully assembled an animal skeleton, they are presented with the option to “learn more” about the given animal. Additionally, a message tells them to find the animal in the gallery. This provides an exit strategy for the player to move on, keeping the amount of time that a group or a child spends in front of the iPad at an acceptable level. Alternatively, if the player decides to leave the game at any time, the interface will automatically restart after one or two minutes of non use. Having a longer than normal timeout period ensures that the game does not restart while the users are still playing, as players need extra time to find the blocks before placing them under the screen.

Initially, I intended for players to be able to post photos of their “weird and wonderful creatures” to a dedicated online gallery, which could be communicated to wider audiences locally and virtually. The idea was that locally, the latest 10 to 15 photos could be displayed on a large LCD screen placed near the table. Virtually, the gallery could have a special page on the museum’s website or blog. Furthermore, I thought the image gallery could be tied in with the museum shop system, so visitors could ”carry” their creation home with them as a framed, printed photo. However, after discussions with the museum experts I decided to remove this option, as it could cause privacy issues (Pokel & Hui, personal communication, January 29, 2015). I revised the design so that the user can still take a photo, but instead of sharing it to a public gallery, they are presented with the option to send it to an email address.

From here, I moved on to the user interface (UI) design sketches. In interactive design, UI refers to the visual design and layout of an application. It is typically informed and guided by UX design.

I had a general idea of how to lay out content and features on screen, which I drafted up into small sketched thumbnails using pen and paper (Figure 36). For example, from the start it became evident that the layout for both device types should have a horizontal orientation to provide a maximal width of view of the animal artwork. From these sketches, I developed a set of basic wireframes with some adjustments, shown in Appendix Q.

When designing the app interface, the two key principles that guided me were simplicity and consistency. Referring to interface design for children, Resnick and Silverman (2005) advise designers to “make it as simple as possible — and maybe even simpler” (p. 119). Another of the well-known rule of interface design is to strive for consistency (Shneiderman, 1998). I attempted to maintain both perceptual and procedural consistency; that is, in *the way things look*, such as the layout, colours and graphic elements, and *how they work*, such as what actions must be taken to achieve a goal. For example, to reveal content that is beyond the current view of the screen (for example, next instructional steps or animal facts), the user needs to swipe the screen sideways. This would be the same for any screen where there is additional content. Another example is keeping the camera icon in the same place across all screens.

To indicate to the user that there are additional pages available through swiping, there are little dots at the bottom of the page; this practice has been widely adopted in interactive media (Neil, 2014). To provide further indication that more content is available, I also added left and right arrows to the edges of the screen. Appendix P for a few design iterations from sketch to final.

Splitting information into sections across several screens was done in an effort to further reduce cognitive overhead, so that the information is presented in small bite-sized pieces, instead of having a large amount of information and images all fitted into in one screen.

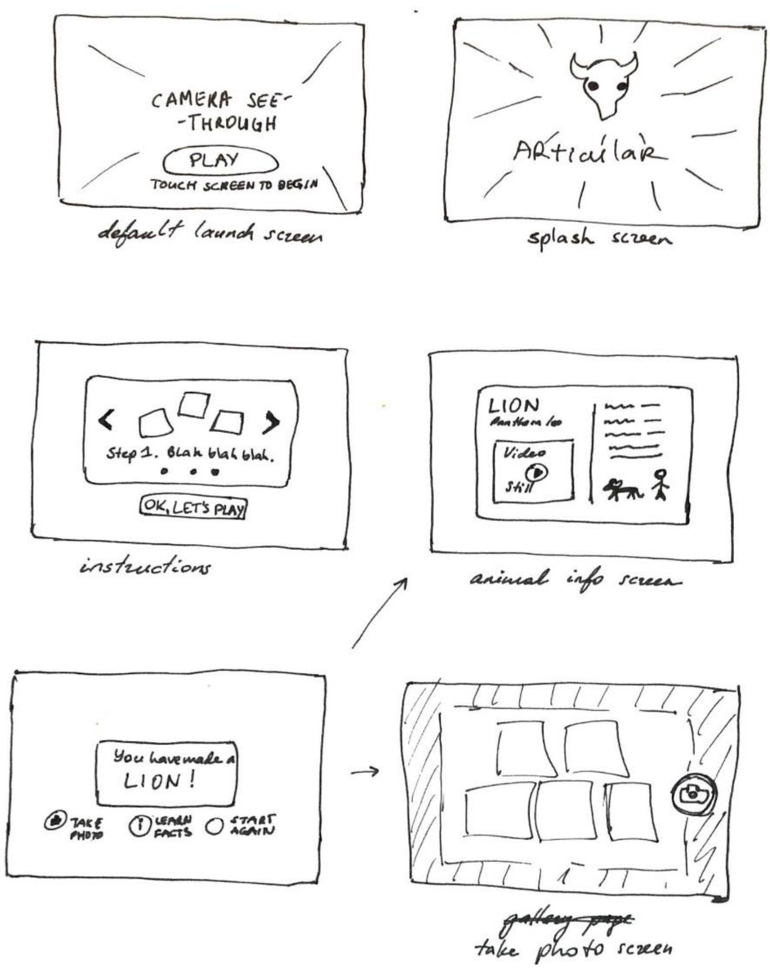


Figure 36. Early iPad UI drafts.

Visual design can draw attention to the game, increase the motivation it provides to players (Whitton, 2014), and reduce cognitive overhead (Kirsh, 2005). Therefore, it is an important aspect of the overall game design. However, visual design is a complex field that encompasses many areas, all of which cannot be discussed in detail in the scope of this thesis. In the following paragraphs, I will address the main aspects of the visual design of the *ARticular* interface.

Design of the interface and graphic elements took a significant amount of time to accomplish. In my design process, I often employ my tacit knowing, intuition and experience. For example, when constructing the layout of a page, I can feel when something is not working. Sometimes I am able to instantly identify the problem and find a solution, but at other times, it is less obvious and I have to approach the problem from several directions, making multiple variations until a solution is reached. Such was the case with the design of the interface. I went through many variation and interaction cycles, some of which are shown in Appendix G, trying to find a balance between a cartoonish design and what I intuitively considered to be appropriate for a museum exhibit. Even with logo design, I experimented with many style options and colours (Appendix H). In the end, I chose a complementary colour scheme of blue and orange for the final design (Appendix I), with dark brown for contrast. Studies show that young children appear to respond positively to bright colours (Parsons, Johnston, & Durham, 1978; Cimbalo, Beck, & Sendziak, 1978; Boyatzis & Varghese, 1994), and think of blue, orange, yellow and green as happy colours (Cimbalo, Beck, & Sendziak, 1978; Boyatzis & Varghese, 1994).

I decided to add a wooden texture (Tarrant, 2011) to some of the graphic elements, such as the splash screen background, to create a more natural look and to tie it in with the tangible part of the game, the wooden puzzle blocks. Figure 37 shows the change that adding the wooden texture made to the splash screen and the menu screen.

Figure 37. ARticular before (left) and after (right) adding wooden texture.

The final layout of content on screen features a “floating” semi-transparent window containing information such as instructions or animal facts (Figure 38). The window is smaller in size than the screen dimensions, so that a view of the real world can be seen behind it. When the window appears at different stages in the game, the view of the real world behind it goes slightly blurry, creating a depth of field.

The background colour of the window is blue, similar to the logotype hue but slightly darkened to reduce strain on the viewer's eyes, as well as to create more contrast with the white text within the window. Wooden texture was not applied to the background element of the window as I felt it made it appear fuzzy and harder to look at. The typeface style selected for headings also mimics the handwritten, cartoonish look, while the typeface for longer bodies of text, such as instructional sentences, is a simple sans-serif typeface chosen for its readability.

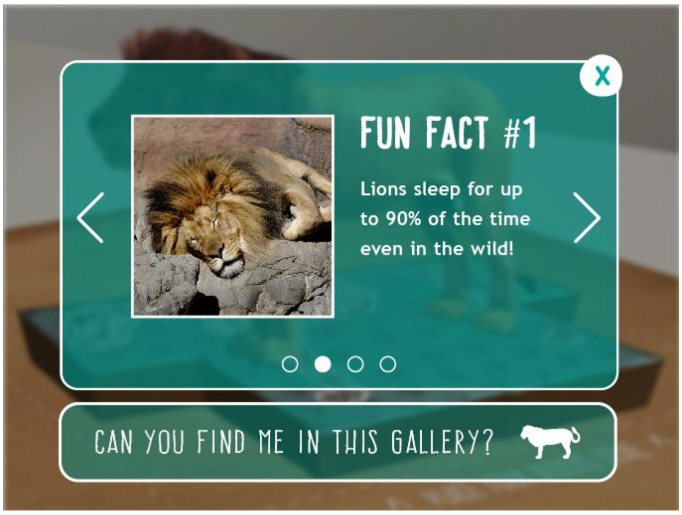


Figure 38. Information screen, showing the 3D model in the background.

Smartphone application design

In order to increase multiuser engagement, a downloadable stand-alone smartphone app version is provided alongside the museum-based iPad version. Visitors can scan the QR code printed on the table mat to download the *ARticular* app to their smartphones or tablets, launch the game and point the camera to the blocks available. Furthermore, if the visitor wants to play the game outside the museum (for example, at home or at school), puzzle blocks can be purchased from museum shop.

The UX and UI of the smartphone app would be similar to the tablet version, but with additional features afforded by the personalisation of a personal smartphone. The initial wireframes I created had multiple features, as illustrated in Figure 39. These included choosing an animal to assemble, competing with friends, and sharing on social networks. However, after further reflection and consultations with a game designer (O. Chernyshenko, personal communication, August 2014 - February 2015), it became evident that it was best to remove or hide some functionality to avoid over-complication. Resnick and Silverman (2005) warn against the ongoing addition of unnecessary functions, known in the industry as "creeping featurism" (p. 119), and advocate simplicity in interactive design for children: "We have found that reducing the number of features often improves the user experience. What initially seems like a constraint or limitation can, in fact, foster new forms of creativity" (p. 119). Furthermore, children have a tendency to click on any apparent button just to see what happens (Halgren, Fernandes, & Thomas, 1995), and this could lead to children getting lost in advanced functionality.

I also realised that some of the original features were inappropriate for the target audience, such as a social sharing button on every screen. Children are not likely to have social network accounts due to age restrictions[3]. Adults wanting to post photos of their child's creations on networks such as Facebook could do so via their phone's photo gallery rather than from inside the app itself. Additionally, if adults wanted to endorse or find the game on social networks, the social sharing feature was moved to the "settings" screen.

Following this reflection-on-action episode, I redesigned the UI to decrease the overall number of features, and restricted access to the settings page with a "child lock". With such a system in place, adults or advanced users can still have these options, but young children would not be able to access them accidentally.

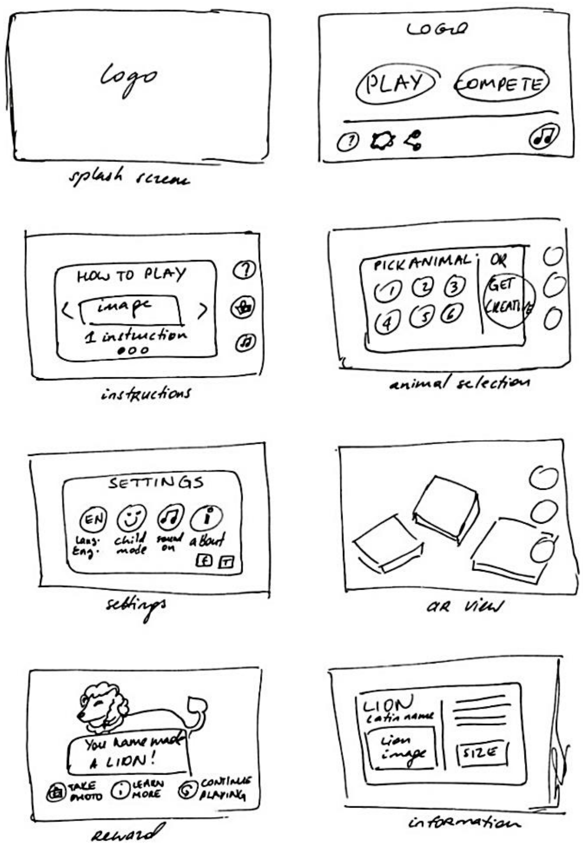


Figure 39. Initial smartphone app wireframes.

[3] For example, to have a Facebook account, you must be at least 13 years old (Facebook, n.d.).

The final menu screen design (Figure 40) contains a prominent "play" button, to allow users to quickly get to the game. Additional features include instructions, settings, and a sound button (by default, sound is on). The UI design of the smartphone application was guided again by the principle "make it as simple as possible" (Resnick & Silverman, 2005, p. 119) to avoid cluttering the main menu with too many options. Revisions of the design can be found in Appendix R.

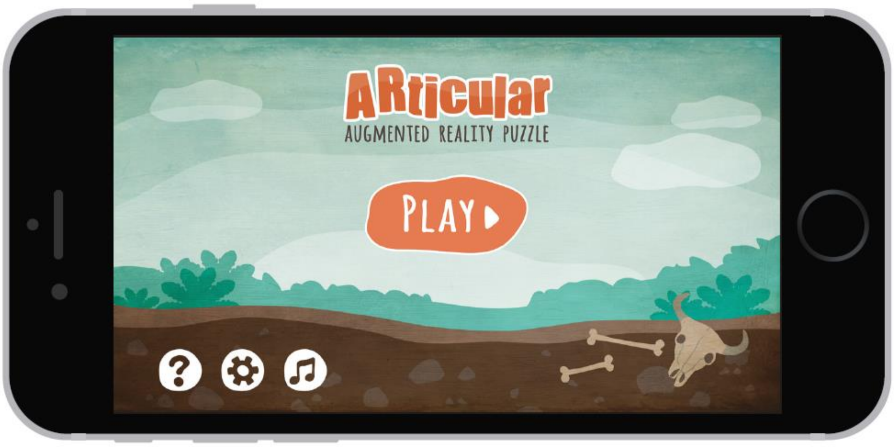


Figure 40. Smartphone menu screen.

Continuing the cartoonish, hand drawn look, the interface icons shown in the menu and throughout the application have a round, uneven shape. This is quite a departure from the initial icons style I was considering at the beginning, as can be seen in Appendix G. Once I developed the artwork, I decided that the cartoonish, round icons were more compatible with the overall visual design of the game.

Furthermore, at the very beginning of the design drafts I had placed the menu icons along the bottom of the screen (Appendix S). However, I soon came to realise that it would be more convenient for the user if the menu icons were all aligned to one side, within the reach of one hand's thumb. This makes it easier to navigate the interface with one hand, while using the other hand to manipulate physical blocks, as illustrated in Figure 41.

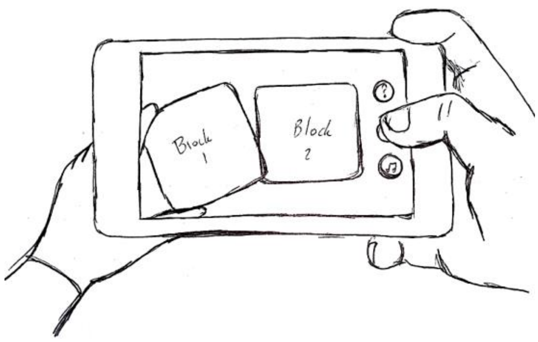


Figure 41. Sketch of the interaction using a smartphone.

The AR interface was kept very minimal to further reduce cognitive overhead. Only three menu options were included: help, photo, and sound on/off. These features are represented by a questions mark, a camera graphic, and a music note symbol, respectively (*Figure 42*). To quit the application, the player needs to press the Home button on the smartphone device itself.

Figure 42. AR view mock-up for the smartphone.

There were several other points of difference in the UI of the smartphone app, as I had to move and modify some icons and graphic elements to suit the smaller screen size of the smartphone. Examples of such changes are shown in Appendix V and Appendix W.

Chapter 5. Description of final concept

In this creative-production project, I developed and presented a concept of an AR puzzle game called *ARticular*, designed for children aged 4 to 8 in a museum setting. The primary design goals of the game are to encourage museum visitor engagement with emphasis on creative exploration and social interaction between visitors, such as collaboration and intergenerational knowledge sharing.

The AR game *ARticular* is comprised of two parts: tangible items in the form of wooden puzzle blocks, and digital content in the form of an AR layer application for Apple iPad (Figure 43). The result is a physical/digital activity where the player engages by grasping, sorting and matching tangible puzzle blocks, viewing the corresponding 2D layers onscreen, and finally viewing the 3D animation and accessing related educational content.

The game features six animals broken into 27 puzzle blocks. The chunky, double-sided wooden puzzle blocks have parts of the animal skeleton structure on the face side. The reverse side is colour-coded in a different colour for each animal, and provides a hint as to the body part. The tactile nature of wood and the visual interest of bright colours are intended to stimulate children's senses. The skeleton outline is embossed, enhancing tactile sensation. The skeleton artwork is stylised as cartoonish line drawings. By using tangible items such as blocks, the puzzle game retains the ease of physical manipulation. Players can freely pick up, hold and rotate the blocks in front of the iPad camera, thus rotating their corresponding AR layer onscreen. The game can be played without the AR display as well, as a traditional puzzle game. Therefore, potential interactions are not necessarily restricted by the limitations of the provided software.

Two types of interaction pathways are facilitated: *construct* or *create*, letting players either reconstruct a particular animal skeleton or create a mixed hybrid. Choosing between these two pathways is not enforced explicitly at the start of the game, but rather happens naturally depending on the player's actions. In either pathway, the AR app initially displays a logically corresponding image for every puzzle block. If an animal skeleton is then accurately assembled, the app rewards the player by unveiling a 3D animated model of the animal with sound effects. By picking up the iPad, users are able to look at the 3D model from different angles. By tapping on the 3D model onscreen, players get access to relevant information about the animal species. Alternatively, the player may choose to create a "weird and wonderful" creature out of mismatched puzzle blocks. In this case, the application will display only the corresponding 2D images for each individual block, without progressing to a 3D animation or related content. In both pathways, at any time, players are also able to take a photo of the AR content visible onscreen, and send it to an email address.

The game is designed for 1 to 3 players (for example, a parent and one or two children, two parents and a child, a couple of friends). Nevertheless, in order to increase multiuser engagement, a downloadable stand-alone smartphone app version is provided alongside the museum-based tablet version. Visitors can scan the QR code printed on the table mat to download the *ARticular* app to their smartphones or tablets, launch the game and point the camera to the blocks available. This also means that visitors can experience the game outside the museum; puzzle blocks could be purchased from the museum shop, or printed out on paper.

In theory, most of the game design is sufficiently general to be used in any informal science learning setting. However, in my study, it was tailored specifically for an existing museum setting which is the W&W gallery in Auckland Museum. In the gallery, the game is set up on a low table, with game components displayed in an attractive and organised manner, creating a pocket of compelling experience. When not in use, the puzzle blocks are held in place within a dedicated container. The provided iPad tablets are mounted on specially designed stands to free up the players' hands while they are manipulating the blocks.

Figure 43. Photograph of *ARticular* game components.
Interface as seen on tablet and smartphone devices, paper mock-ups of the puzzle blocks and table mat.

ARticular offers its audience physical and digital interactions, different interaction pathways, and a variety of content and features. Additionally, the design of the game facilitates social interaction through which learning can be shared. Specifically, *ARticular* is designed to facilitate the following aesthetic principles:

Collaborative engagement: The social interaction encouraged by *ARticular* can lead to collaborative problem-solving, as players help each other find related puzzle pieces.

Creative exploration: Creativity is supported by allowing players to design their own "weird and wonderful" creature. This pathway creates an opportunity for open-ended exploration.

*Educational value: T*he potential learning benefits of the game include learning about the characteristics of selected animal species, as well as developing cognitive and physical skills involved in problem-solving a puzzle game.

Intergenerational knowledge sharing: The game fosters reciprocal learning relationships by engaging children with new technology and content together with adults who are able to support children's learning. For example, having a more knowledgeable and experienced adult explain some anatomical concept to the child, or simply reading the information to a child who may be too young to read. Alternatively, some elderly adults such as grandparents may struggle with new technologies such as iPads, yet their grandchildren may have a better grasp of such devices, and will demonstrate how to interact with them.

Finally, although it was not a criterion for the evaluation of the concept design of this study, feedback from the Auckland Museum was quite positive in terms of how they saw the game could potentially engage visitors in the W&W gallery, with the museum expressing interest in implementing the game design concept on the museum floor (Pokel & Hui, personal communication, January 29, 2015). This surprise outcome suggests the real-world relevance of technology-based museum experiences of this type.

Reflections on the game design

Having completed the game design concept to the stage presented in this thesis, I had further reflections relating to the overall game design, summarised below.

Complexity: Although it seemed possible to me that the game could be played with children as young as four (especially in the presence of an adult to support them), further research is needed to confirm this.

Positioning precision: Although a reasonable sensitivity area has been defined in Unity, young children may still struggle to place blocks side by side accurately enough to trigger the 3D animal model. Ways of improving precision would be explored, such as adding magnets, or increasing the sensitivity area. Alternatively, simply providing very clear instructions about the importance of precision might mitigate this issue.

Name: In retrospect, the definition of the word articular may not be too apparent or known to visitors, especially children. It is important to come up with a name that reflects the nature of the game and resonates with users, hence further exploration is needed to settle on the name.

Adding information levels to the smartphone app: This refers to expanding the smartphone version of the game to include several layers of AR content such as bone names, muscles, and additional anatomical or zoological information. Such an approach may make the game more appealing to users of different ages and abilities (Halgren, Fernandes, & Thomas, 1995).

Adding competition option: This idea was considered in the beginning of the project, but rejected for the sake of simplicity. However, I still think that aspect would be interesting to investigate further.

Menu icons: I am not certain whether the meaning of symbols without words on the main menu is clear to children, however, it is hoped that this is another aspect of the game that can be explained by the adults.

Animal selection: The selection of available animals could be expanded to include several thematic sets, such as safari animals, marine creatures, and New Zealand fauna. New sets could be released periodically to update the game content. Notifications of the updates would be sent to users via the smartphone app.

Reflections on the creative-production project

My concept was developed from a combination of my own vision, tacit knowing and experimentation, reflection, relevant literature, examples, and expert advice. In Figure 44, I attempt to visualise my journey through the development of *ARticular*, showing the relationships and connections of different considerations I encountered along the way. Although this is an attempt to give linear structure to the design process in a fashion of “A informs B informs C”, in practice, at any point any design consideration was intertwined with the other considerations, and there was a high degree of back-and-forth movement between all topics in the course of this creative-production project.

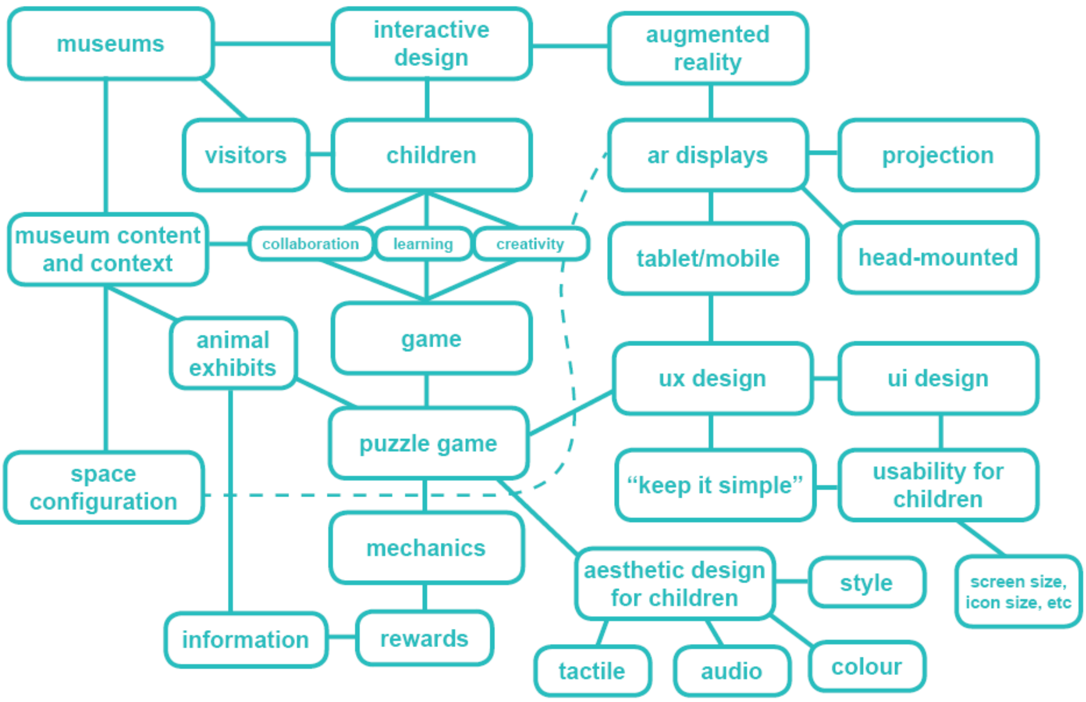


Figure 44. Mind map of key interests and considerations in the creative-production process of *ARticular*.

The reflection-on-action technique was a demanding task in the sense that it requires the researcher to consciously step aside and note down reflections, which felt uneasy at times, such as when I was engrossed in the creative process or absorbed in literature, searching for new knowledge about a specific topic.

Given more time, resources, research and expertise, more development could have taken place to produce a fully-functional, self-contained application prototype of the application in both of its forms: museum-based tablet and personal smartphone, as well as a set of tangible wooden blocks. This prototype would enable user-testing. Even though it was outside of the scope of my research, and as much as I tried to seek out knowledge to inform my design decisions, I often felt that aspects of my design lacked validity because I was not able to evaluate the game through user-testing.

In retrospect, perhaps I could have presented aspects of my game design to a small focus group of children of appropriate age to get their feedback. Researchers suggest that children's games should ideally be designed with input from children (Bruckman & Bandlow, 2002; Druin, 1999; Jensen & Skov, 2005) at various stages of the creation process. This could be worth exploring as a potential future research direction.

Chapter 6. Conclusion

In this creative-production project, I developed and presented a concept of an AR puzzle game called *ARticular*, designed for a museum setting and targeting children aged 4 to 8. The primary design goals of the game are to encourage museum visitor engagement with emphasis on creative exploration and social interaction between visitors, such as collaboration and intergenerational knowledge sharing.

The concept of *ARticular* was conceived through an iterative design process involving experimentation and reflection, ongoing contextual literature review, discussions with the expert reference group, as well as drawing on my own tacit knowing in digital media. Theory was put into practice by developing a concept of the overall experience as well as detailed application design and artwork. Prototyping aspects of the required AR functionality in Vuforia and Unity confirmed the technical feasibly of the game.

Naturally, the next step would be to develop the concept into a functional prototype. This research can be viewed as the “design phase” of a larger project, with the next phase being the development of a prototype for formal evaluation, followed by deployment of the exhibit on the museum floor. By letting visitors freely play with the application, observational sessions could provide further insight into the visitor experience afforded by the game design. It would also be interesting to assess the learning outcomes of the game, and to compare them to learning outcomes obtained through playing the game without the digital AR component.

Limitations

Certain technological factors affected the design of the game. The UI interfaces presented herein are designed for Apple iPad and iPhone, two consumer devices popular at the time of writing. The choice of Apple devices for the app is for convenience, as these were available to the researcher for testing the design drafts, and does not imply a preference over Android or any other platform. If the game was to be developed into a real-world application, it would support multiple platforms, including a downloadable app for personal tablet devices, not only smartphones. The AR functionality is designed for Vuforia and Unity, and is thus bounded by the limitations of these tools. It must also be noted that the creative outcome document does not contain every possible screenshot in the game. The screenshots provided show the key points in the user experience, to demonstrate game mechanics and aesthetics. Furthermore, the animal-related information displayed in the screenshots, such as animal "fun facts"[4], serves to illustrate the concept only, and not for assessment in terms of scientific accuracy.

[4] Textual contents for the "fun facts" section was taken from the Auckland Zoo website (Auckland Zoo, 2015).

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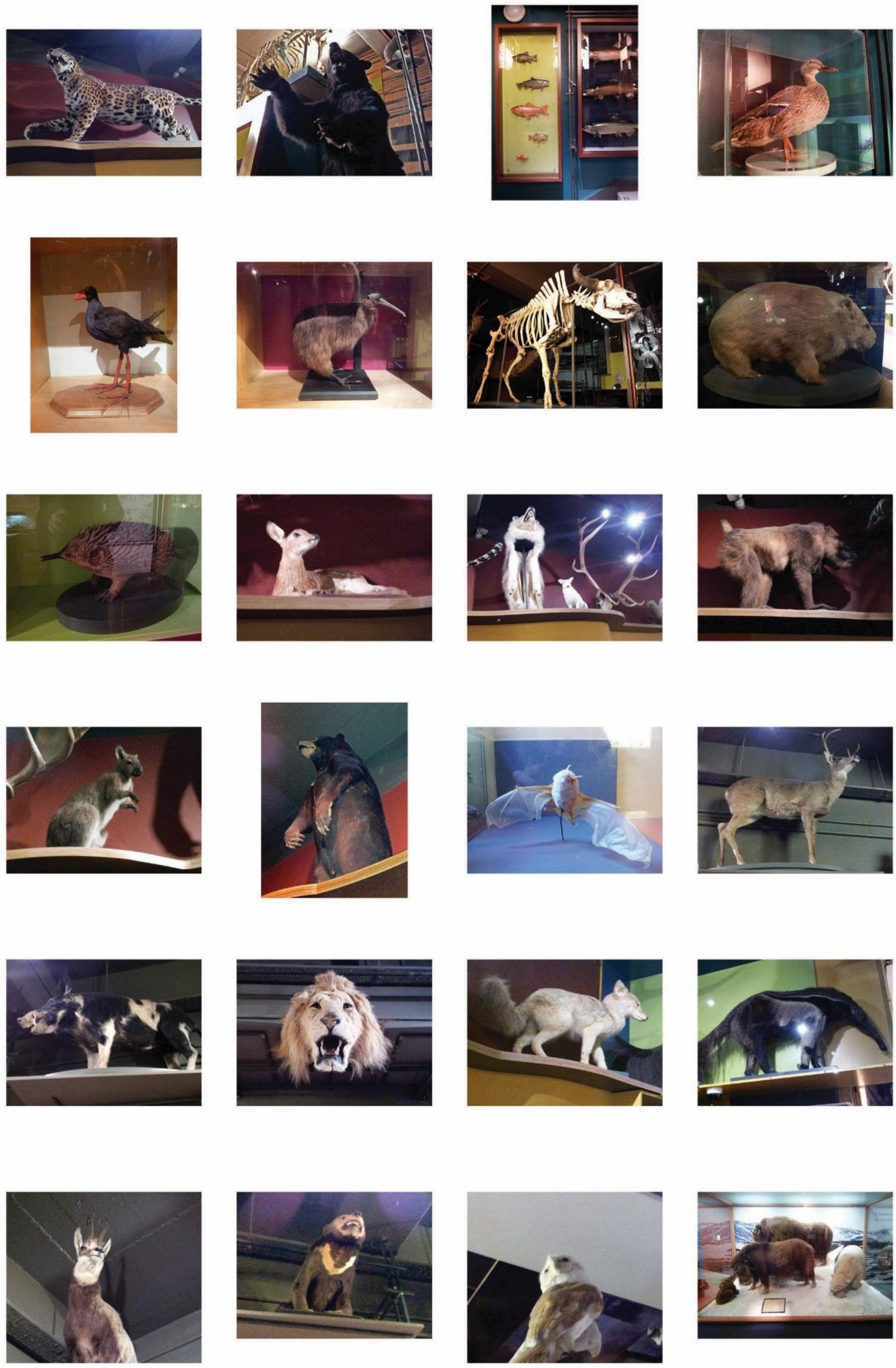
Appendices

Appendix A

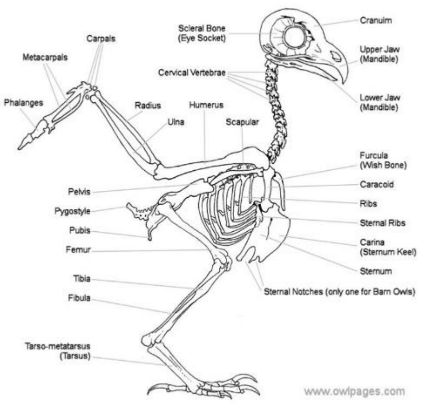
AR station at W&W gallery.

Appendix B

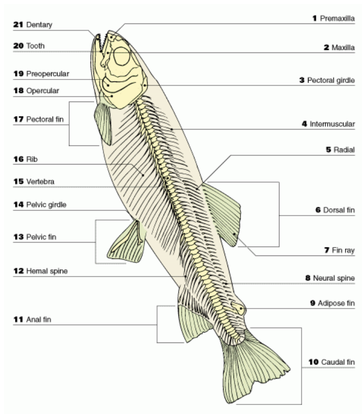


Part of the taxidermy collection at the W&W Gallery
in Auckland Museum.

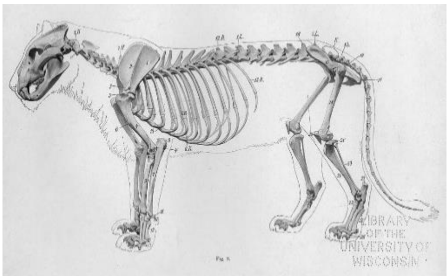
Appendix C



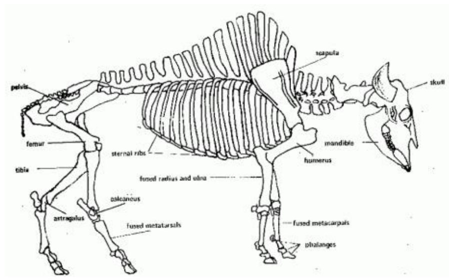
Owl Skeleton. Retrieved from http://www.owlpages.com/image.php?image=articles-Owl+Physiology-Skeleton-01. Copyright Deane Lewis. Reprinted with permission.



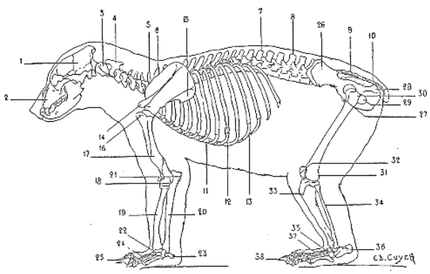
Trout Skeleton. Retrieved from http://www.fofweb.com/Electronic_Images/onfiles/SciAni Anat5-22c.gif. Copyright by Diagram Visual Information Limited. Reprinted with permission.



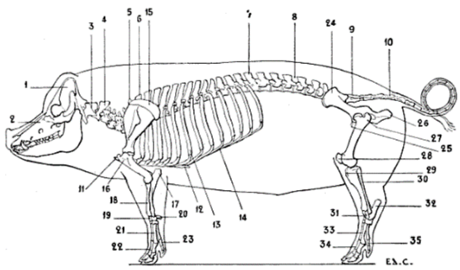
Lion Skeleton. From "An atlas of animal anatomy for artists," by W. Ellenberg, H. Dittrich and H. Baum, 1956. Copyright by Dover Publications, Inc.. Reprinted with permission.



Bison Skeleton. Retrieved from http://www.texasbeyondhistory.net/kids/images/bison%20skeleton.gif. Copyright by Texas Beyond History, Texas Archeological Research Laboratory, University of Texas at Austin. Reprinted with permission.



Bear Skeleton. Retrieved from http://www.gutenberg.org/files/38315/38315-h/38315-h.htm. Public domain.



Pig Skeleton. Retrieved from http://www.gutenberg.org/files/38315/38315-h/38315-h.htm. Public domain.

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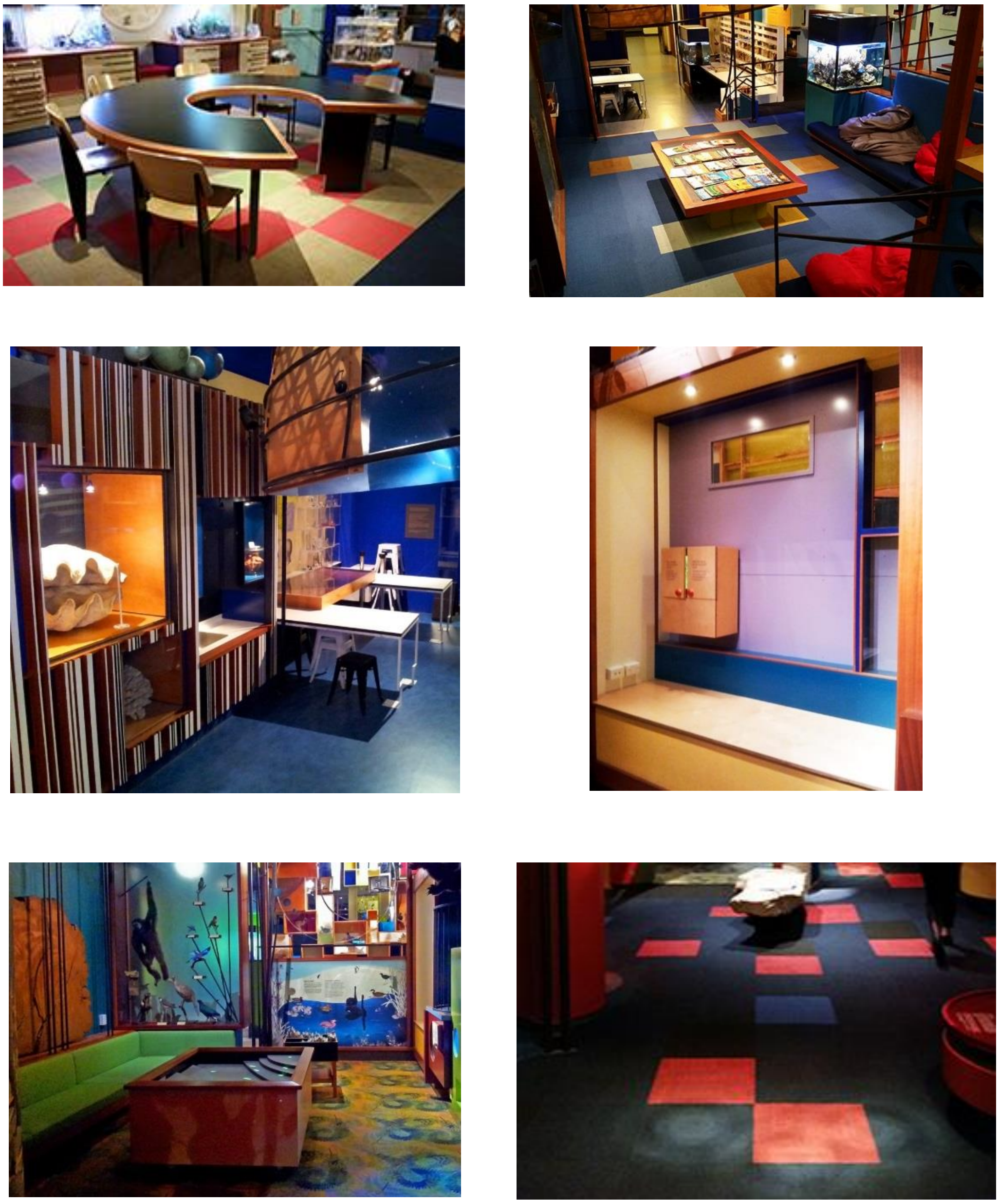
Appendix D

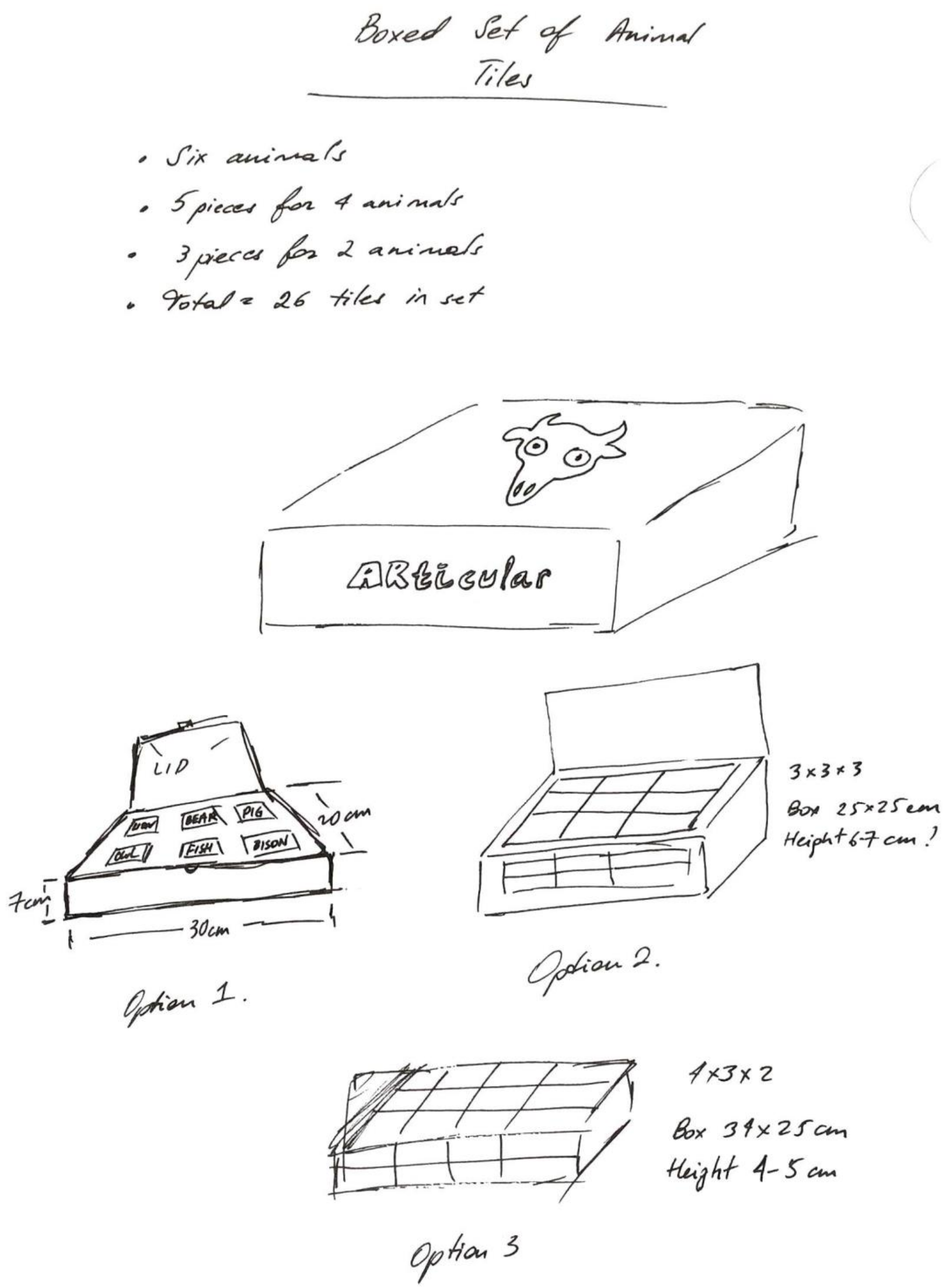
Initial concept development based on the word articulate.

Appendix E



Several areas within the W&W gallery were considered as potential sites for the installation of *ARticular*.

Appendix F



Sketches of ideas for the puzzle container.

Appendix G

Drafts of design variations for smartphone UI.

Appendix H

App icon design iterations – exploring various colour schemes and background textures.

Appendix I

Source: Colour Scheme Designer 3. colorschemedesigner.com/csd-3.5

Colour scheme research for *ARticular*.

Appendix J

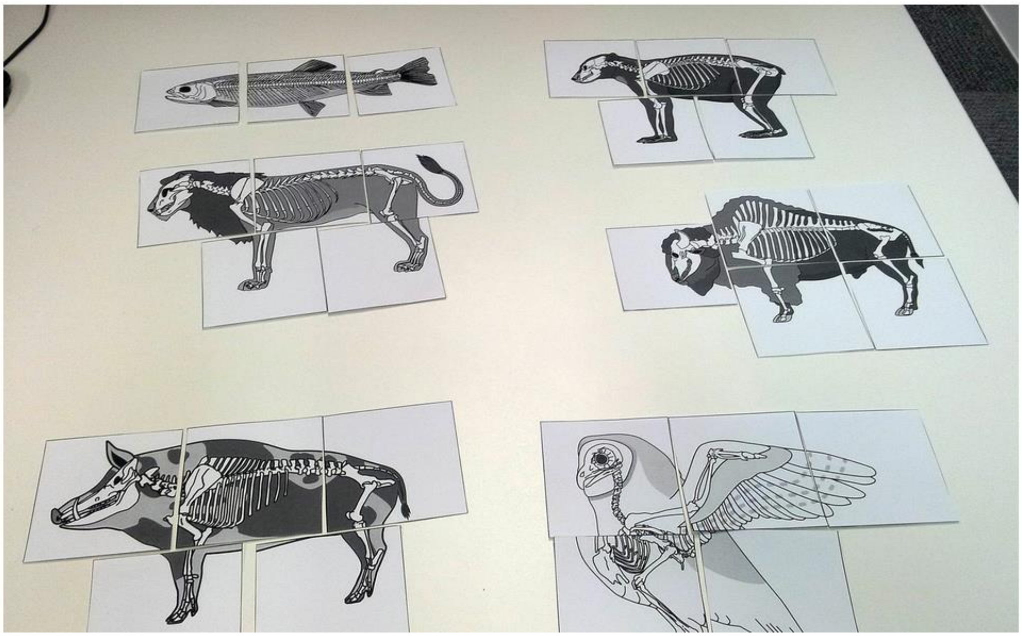
Puzzle piece dilemma

Trying to improve the position of animals on the puzzle pieces.

Should all animals be spread across the same amount of pieces? I think not. The fish, for example, fits best on only tree pieces.

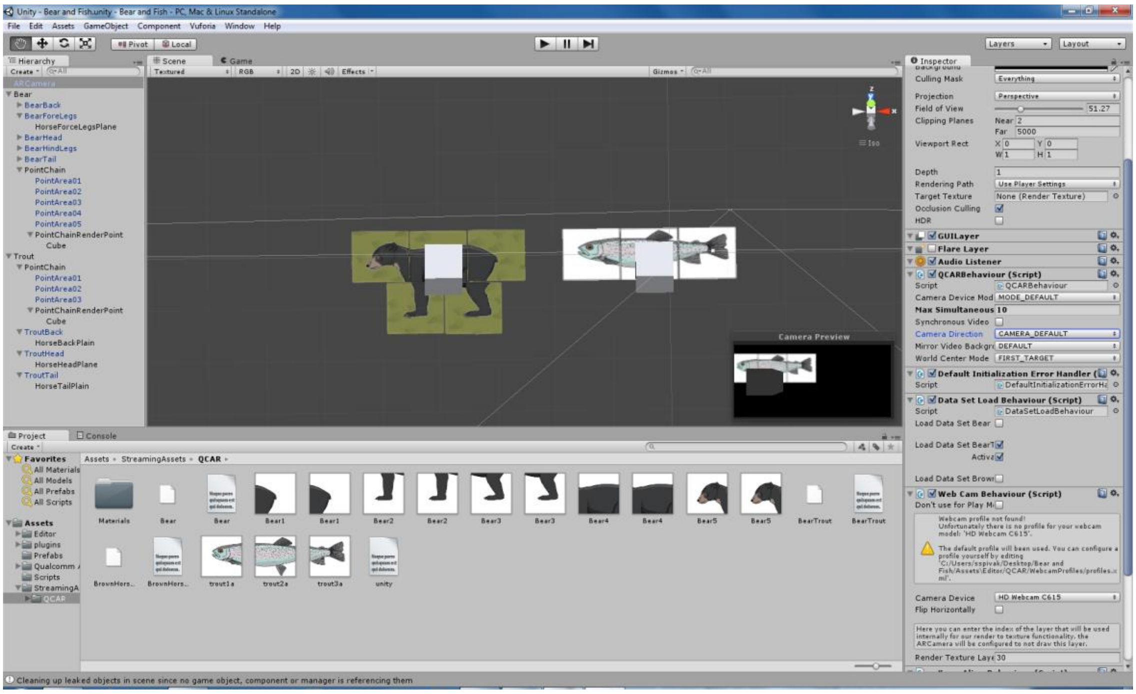
Should the arrangement of the pieces be the same for lion, bear, bison and hog, i.e. top row 3 pieces, bottom row 2 pieces, centre aligned? The bison's body doesn't fit neatly on such an arrangement...

The owl, spread across 5 pieces, is far too big compared to the other animals. While it was decided that the animals need not be to scale, precisely, I think it's not good to have such a large owl. I'm going to try shrinking it down to four pieces. Should I make the bison larger, then?



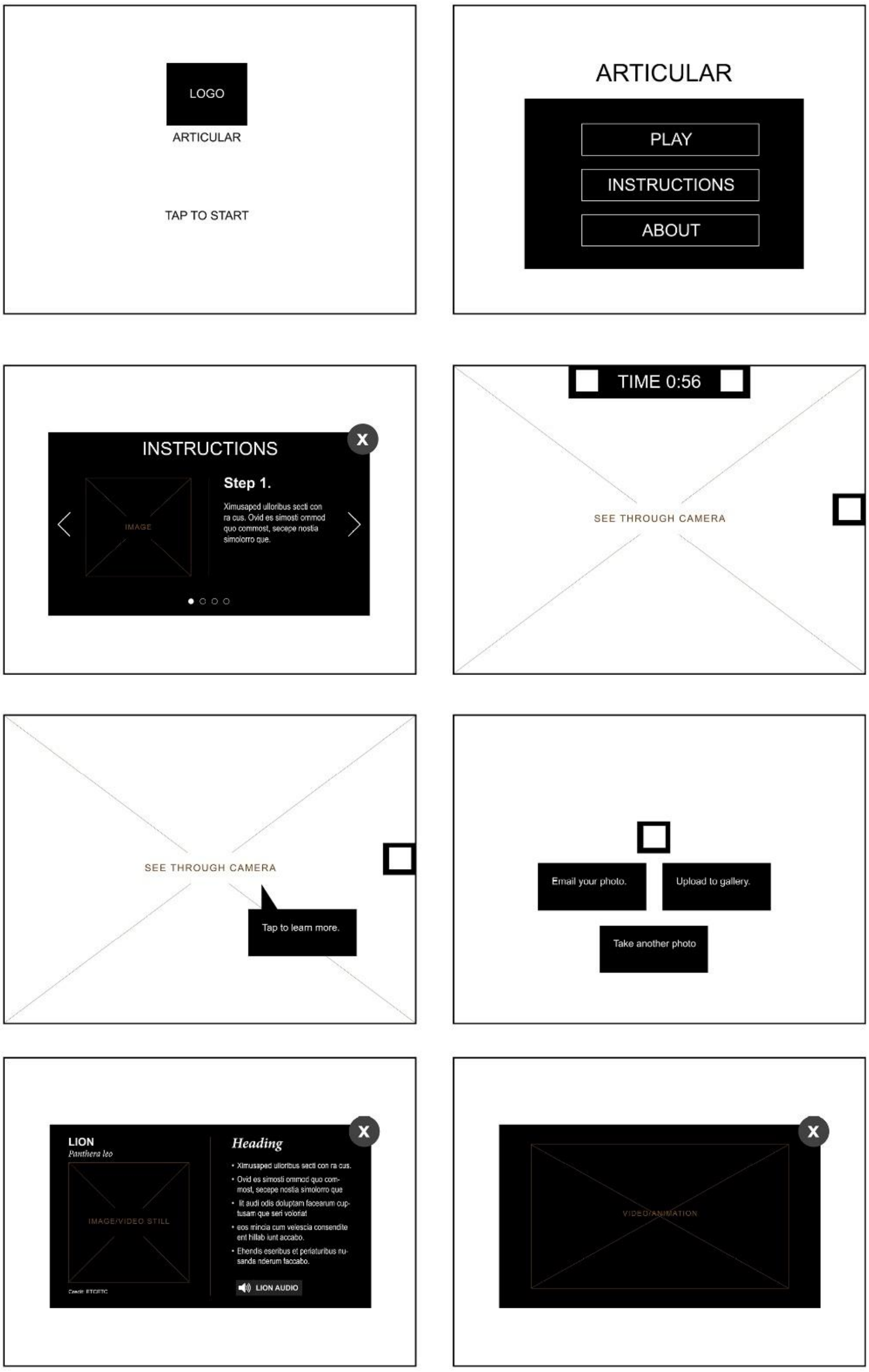
Reflections on puzzle piece design recorded in Evernote.

Appendix K



Unity/Vuforia experiments, showing two completed animal skeletons with 3D object over them. *Note*. In this screenshot, the 2D overlay images are still being displayed simultaneously with the 3D objects, but should not appear in the final application design.

Appendix L



Wireframes of iPad interface developed in the early stages of the project.

Appendix M

Deciding between table mat colour scheme options.

Appendix N

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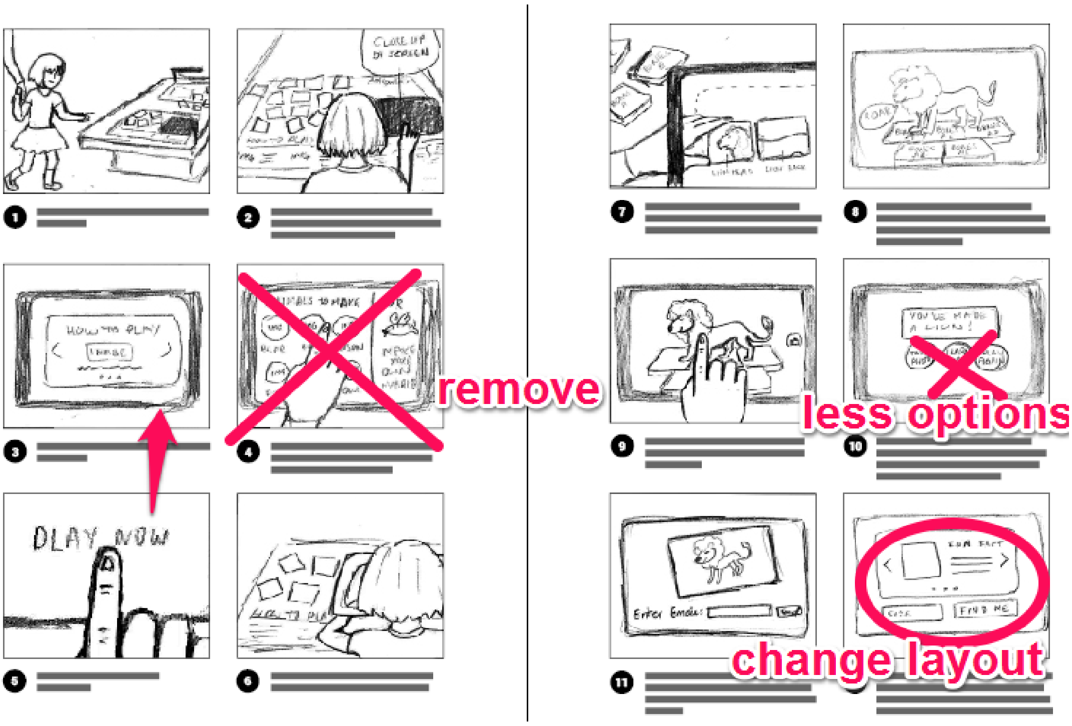
by the author of this thesis
for copyright reasons

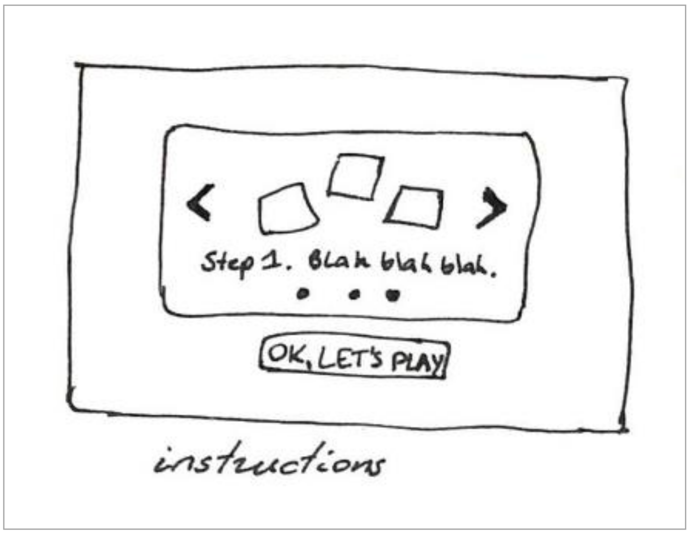
Examples of unrealistic animal scale in children’s puzzle games.

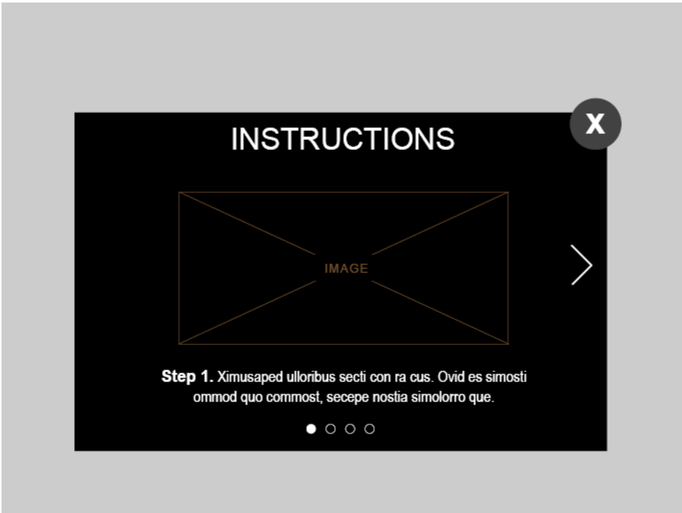
Appendix O

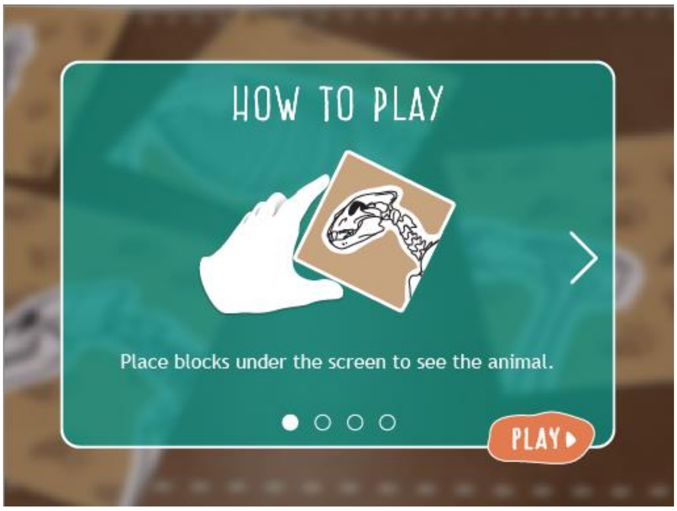


Changes to user journey.

Appendix P

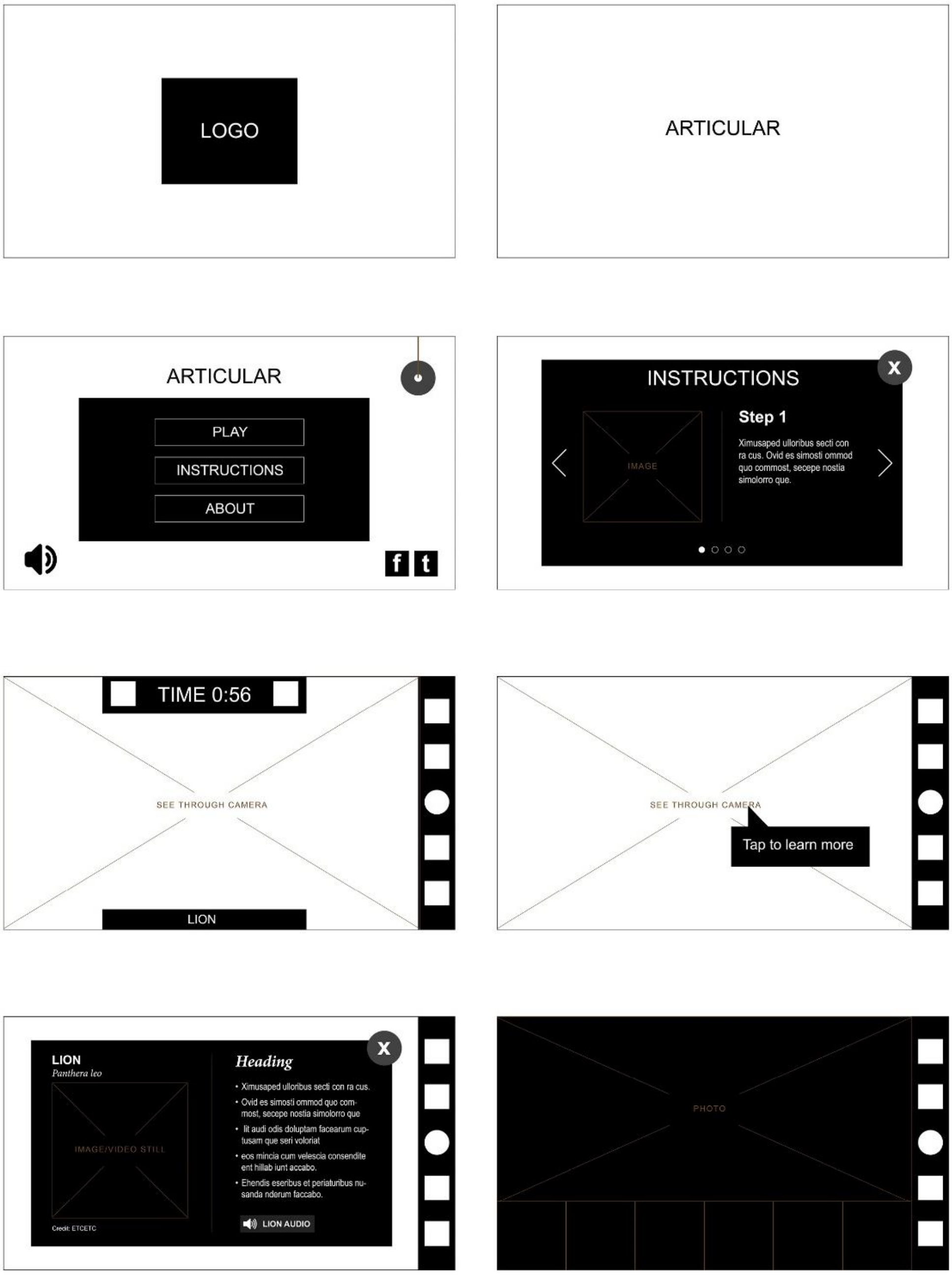






Instruction page design iterations.

Appendix Q

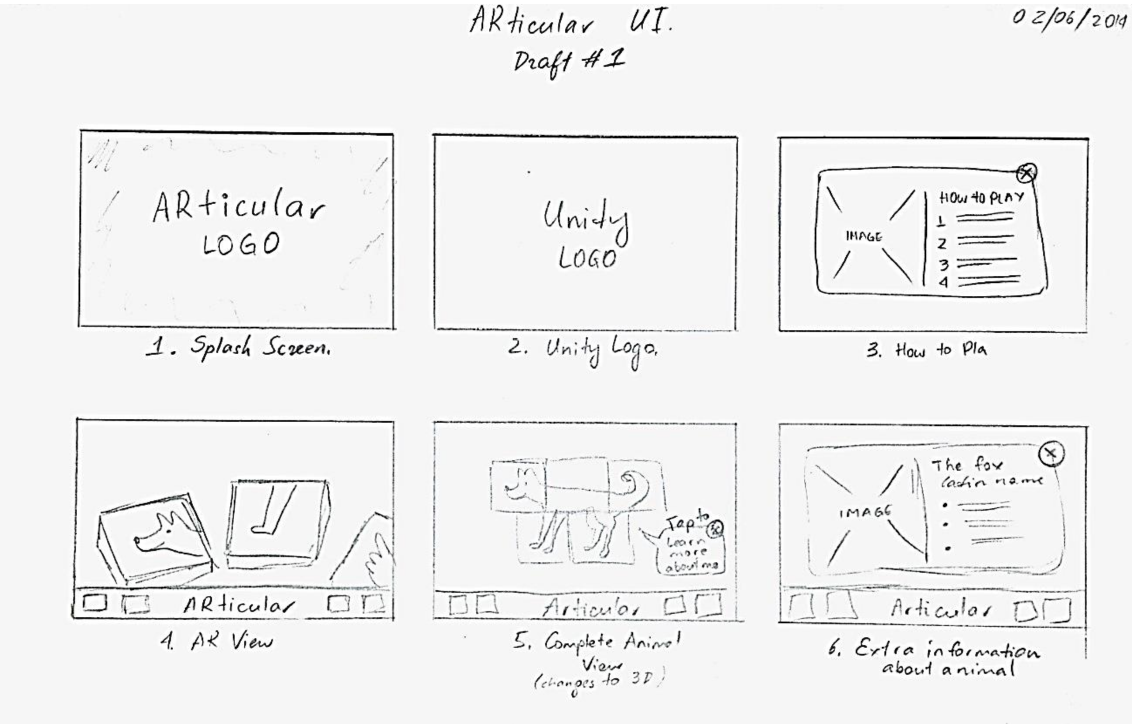


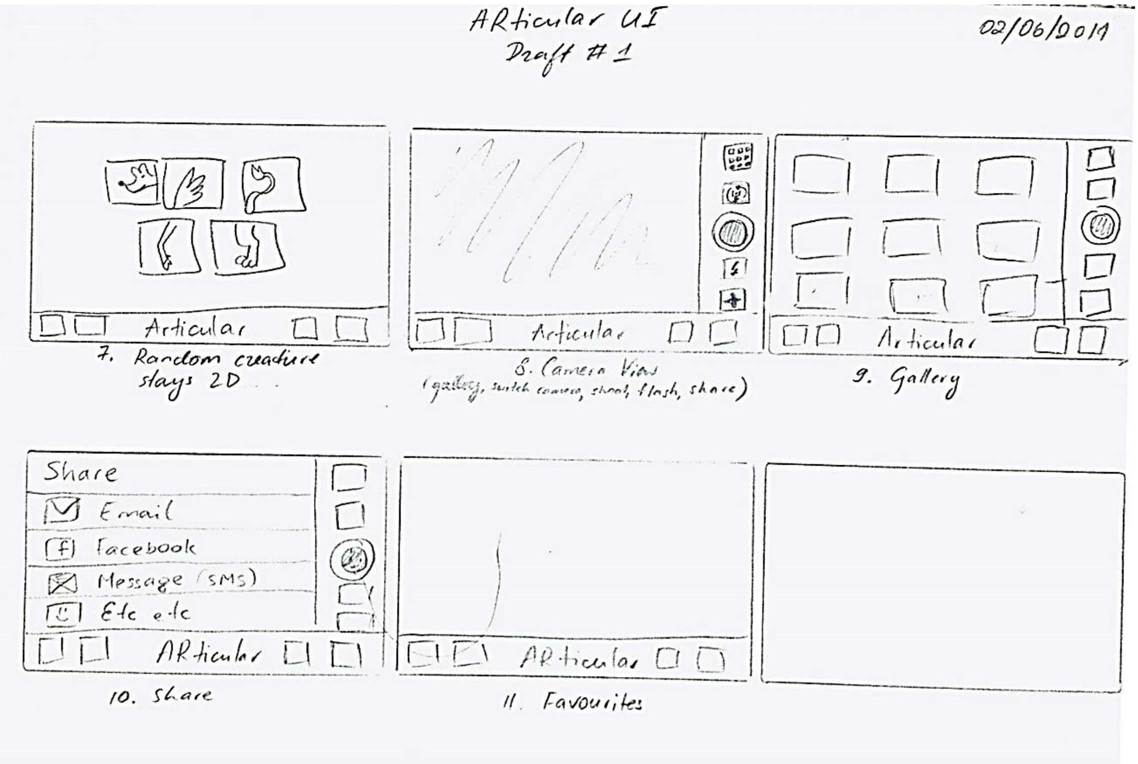
Wireframes of smartphone interface developed in the early stages of the project.

Appendix R

Later stages of menu screen iterations leading to final design.

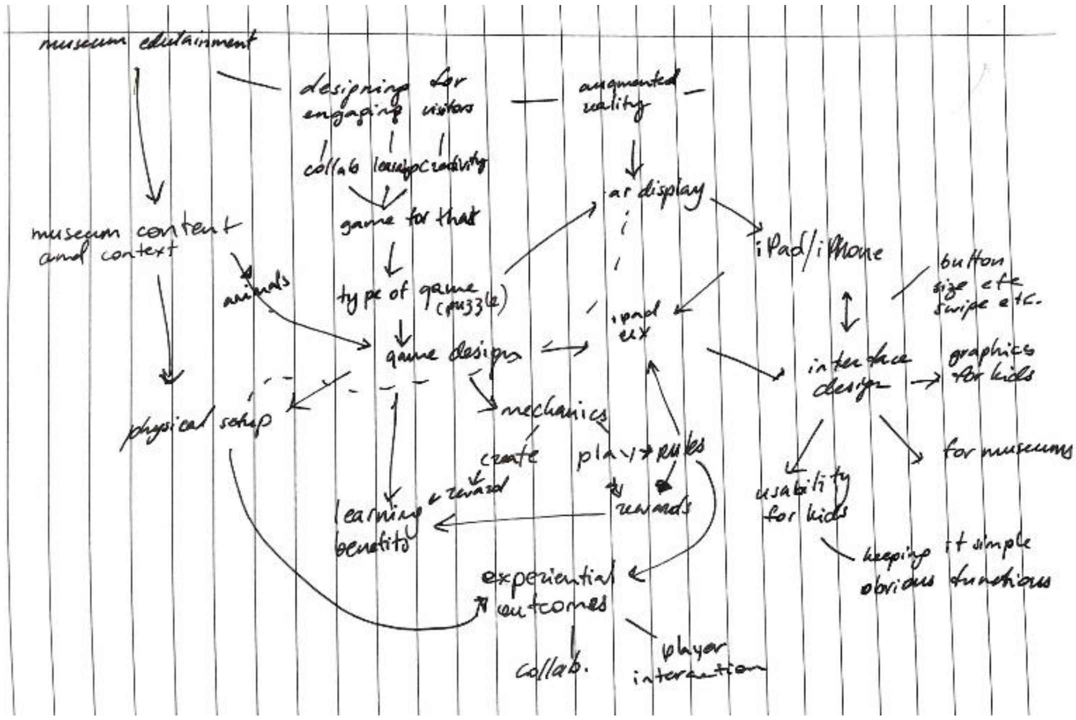
Appendix S





Initial set of wireframe sketches for the smartphone application.
Many of the original design features were rejected or modified in the end.

Appendix T



Sketch of the flowchart of key interests and considerations in the creative-production process of *ARticular*.

Appendix U

Gmail
by Google

Sophia Spivak <soph.spivak@gmail.com>

Thank you for purchasing a 3D model at CGTrader!
1 message

CGTrader <info@cgtrader.com> Wed, Mar 4, 2015 at 11:30 AM
Reply-To: CGTrader <info@cgtrader.com>
To: soph.spivak@gmail.com

cgtrader

Hi !

Thank you for purchasing a 3D models at CGTrader! Here are the purchase details:

Product	Author	Price	Status
LION	deespona	$20.10	Paid

If you have not dowloaded it yet, you can download the models at http://www.cgtrader.com/orders/22601/8ab42ac5-a4ae-49b6-97d0-a597469a5aa2. You can download it as many times as you like.

If you have any questions, just respond to this email and we'll help you!

Download your model!

Screenshot of email confirming 3D model purchase from www.cgtrader.com

Appendix V

Modification of the instruction page for the smartphone app.

Appendix W

Modification of the 3D object view for the smartphone app.