THEORY INTO PRACTICE: "DOMAIN-CENTRIC HANDHELD AUGMENTED REALITY GAME DESIGN" FOR DESIGNERS

KOH KOON CHUAN RAYMOND

NATIONAL UNIVERSITY OF SINGAPORE

2013

THEORY INTO PRACTICE: “DOMAIN-CENTRIC HANDHELD AUGMENTED REALITY GAME DESIGN” FOR DESIGNERS

KOH KOON CHUAN RAYMOND

(B.DES, AUCKLAND UNIVERSITY OF TECHNOLOGY, NEW ZEALAND)

A THESIS SUBMITTED

FOR THE DEGREE OF

MASTER OF ARTS (INDUSTRIAL DESIGN)

DIVISION OF INDUSTRIAL DESIGN

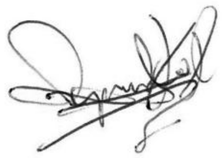
NATIONAL UNIVERSITY OF SINGAPORE

2013

DECLARATION

I hereby declare that the thesis is my original work and it has been written by me in its entirety. I have duly acknowledged all the sources of information which have been used in the thesis.

This thesis has also not been submitted for any degree in any university previously.



Koh Koon Chuan Raymond

31 December 2012

Acknowledgements

The author would like to express his utmost appreciation to Dr. Henry Been-Lirn Duh for his extensive research training, supervision, inspirations and advice, as well as for the many opportunities and resources, including this candidature. His strong support made this research possible. The author would also like to thank Dr. Yen Ching Chiuan for the opportunity to take up this candidature under his supervision in the Division of Industrial Design, National University of Singapore (NUS). Finally, the author would like to acknowledge the invaluable advice and support from his publication co-authors (full listing in Appendix H), external collaborators, colleagues and friends, without whom many aspects of this interdisciplinary research would not be complete. Particular mentions:

1. Research Design - HCI Domain (Study 1): Yu-Ning Chang, Institute of Communication Studies, National Chiao Tung University, Taiwan

2. Research, Experimental Design and Data Analysis for User Study - Education Domain (Study 2): Yun-Ting Wong, Keio-NUS CUTE Center, NUS

3. Technical Development for "The Jackson Plan" game prototype (Study 3): Cheng-Ho Chen, Keio-NUS CUTE Center, NUS

4. Host Research Institution: Mobile Interactive Media and Entertainment Lab @ Keio-NUS CUTE Center, NUS (2011-2012)

5. External Collaborators for "The Jackson Plan" game project (Study 3):

* Design School, Singapore Polytechnic

* Outram Secondary School, Singapore

6. Funding: This research is partially funded by project no. WBS R-705-000-025-271, a grant from the National Research Foundation through the Ministry of Education of Singapore, and project no. WBS R-705-000-029-592, an industry research grant from Singapore Technologies Electronics (Info-Software Systems).

7. NUS Institutional Review Board - Approval Number: NUS 1623 / NUS-IRB Reference Code: 12-224 / Date Approved: 5 July 2012 **(Study 2)**.

Summary

New media technologies have always unravelled design issues and opportunities for designers, developers and users alike. The rapid developments of both Augmented Reality (AR) and sophisticated mobile technologies that revolve around smart and sensory features have raised profound interests in the designs of handheld AR (HAR) games or game-like user experiences. As extensions of fun games, these experiences can be used to support various formal and informal activities (such as learning, training and touring) in the real world on highly pervasive mobile devices, including smart phones and tablets. Studies in this area however did not draw explicit attention towards possibly exploiting the inherent characteristics of embedded and ambient technologies to impact design and conceptualization processes of such media. These include considerations for designing game activities, game mechanics, user interactions, user experiences, and the co-creativity processes of collaborations in design. One fundamental gap for designers to work with HAR game media is manifested as missing design guidelines to fuse knowledge domain (theory) with features of the evolving new AR technology into tangible rule-based designs. This gap is attributed to the highly interdisciplinary nature of AR and smart technologies that typically require an initial understanding in disciplines of Computer Science, Engineering, Design, Game Design, and Social Sciences. To address this gap, a multi-part research has been conducted using "Education" as a case domain for HAR game design. It consists of 3 studies that are centered on a conceptual framework that dictates a triarchic and coherent interplay between system, application and

interaction elements to support the formulations of early design considerations for HAR games (Study 1). Thereafter, a game design model is proposed for structuring knowledge (educational) requisites that are grounded from a selected operationalizing theory into the practical game design and development process. Based on the proposed model, the design, implementation and evaluation of a game prototype for situated history learning as a case for translating theoretical considerations into game, knowledge-based design styles and interaction designs are shared. The evaluation with secondary school students validated transfers of the intended communication goals (applied understanding of knowledge-based content) of the contextual game media (Study 2). Real-world issues during prototype's design and development in Study 2 are examined to elaborate on the proposed game model's practical usage. A co-creativity case is reported where two students from a design school played dedicated artists' roles for art and game design developments respectively. Theoretical learning and curricular elements were translated to meet the communication requirements of the project through knowledge-based design strategies. The interdisciplinary research and development collaboration also relates how a clearer understanding of such didactic situations can empower and invoke co-evolutions of both art and technology in HAR as a new media to design gaming experiences (Study 3). The proposed game design methodology consisting of the game framework and model is presented as the contribution of this thesis. Application strategies and guidelines are summarized for designers in the respective studies. To conclude, implications for the three studies are discussed to highlight possible directions for future work.

Table of Contents

List of Tables

List of Figures

Chapter 1. Introduction

1.1 Augmented Reality

New media technologies have always unravelled design issues and opportunities for designers, developers and users alike. Augmented Reality (AR), as commonly defined, is the presentation of virtual content that is registered in 3D in the physical real world that features interactions in real-time (Azuma, 1997). In an older Virtuality (VR) continuum proposed by Milgram and Kishino (1994), AR is described only as a possible manifestation of Mixed Reality (MR), which characteristically brings together real and virtual elements within a single display (Figure 1). It is analogous to the concept of ubiquitous computing by Weisser (1991) where large numbers of computers and displays are described as embedded in the real world so that they are an extricable and socially invisible part of our surroundings. By utilizing projection displays and cameras, information may be projected on and read from the environment (Wellner, 1991).

Figure 1. Reality-Virtuality continuum. (Source: Milgram, 1994)

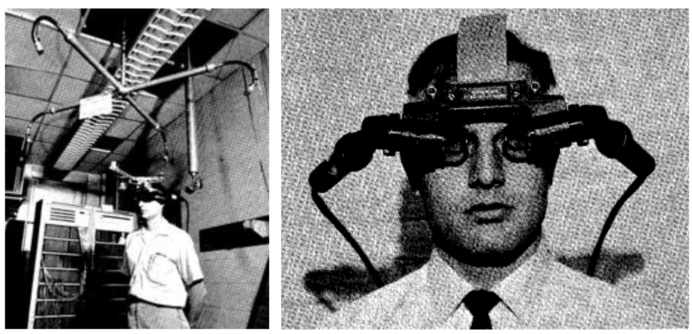


Figure 2. The first AR/VR system. (Source: Sutherland, 1968)

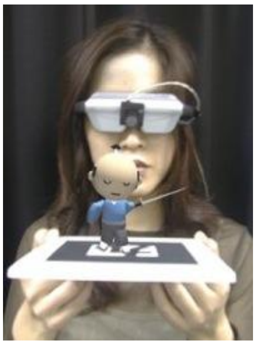


Figure 3. A 3D model on a fiducial augmented reality marker seen through a head-mounted display. (Source: Kato and Billinghurst, 1999)

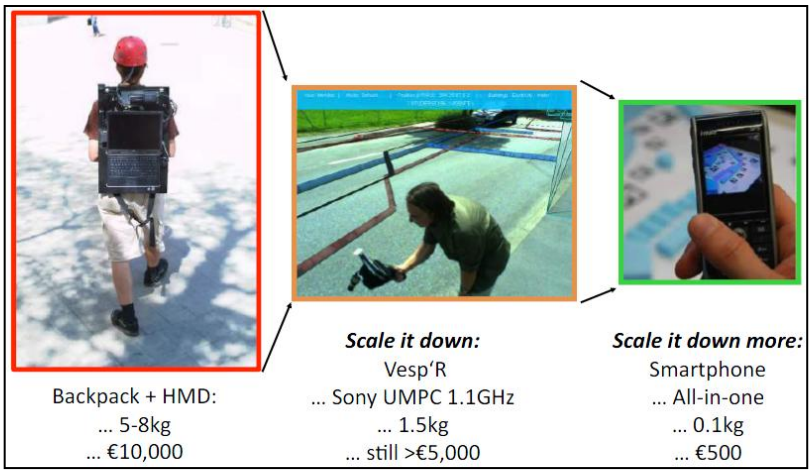


Figure 4. Lighter, smaller and cheaper mobile augmented reality systems. (Source: Mulloni and Wagner, 2010)

AR has come a long way since its first original conception by Sutherland, (1968) in Figure 2 that utilized a Head-Mounted Display (HMD) to track the user's head position and orientation as in Kato and Billinghurst's (1999) work in Figure 3. As a natural complement to mobile computing research over the years (Wagner, 2007), AR has today for various purposes found a place in handheld form as illustrated in Mulloni and Wagner's (2010) work in Figure 4. This phenomenon can largely be attributed to the rapid concurrent developments of both Augmented Reality (AR) and sophisticated mobile technologies as platforms for synthetic information representations (as shown in Wagner's (2007) illustration in Figure 5) (Chang, Koh, and Duh, 2011). The field of AR is interdisciplinary, spanning theories, research and discussions from several affiliated disciplines other than computer science and engineering that attempt to inform information presentations through design from various perspectives; mobile design and information visualization in the field of human computer interaction (HCI) for user interfaces and interactions on screen-constrained devices; visual clutter; perception and attention focus issues in cognitive sciences; multimodal and collaboration issues in communications; form factors of AR in industrial design; game mechanics in game design, etc.

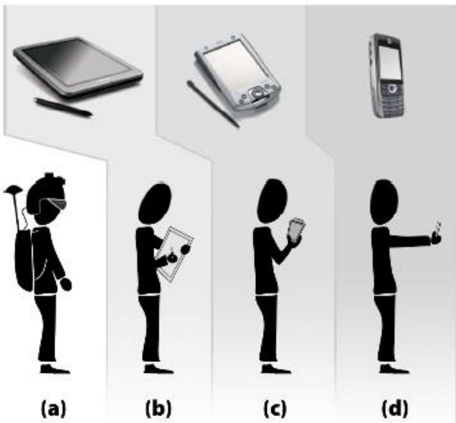


Figure 5. Affordances of mobile augmented reality systems
(a): Traditional "backpack system" and HMD, (b): Tablet PC, (c): PDA, (d): Mobile phones. (Source:Wagner, 2007)

Mobile technologies that exploit "smart" and sensing features enable the presentations of user, device or ambient related information (i.e. users' physical locations, user-generated multimedia content, user and environmental contexts, connectable digital network protocols such as WiFi and Bluetooth, orientations of devices being used, embedded sensor data, and larger datasets such as weather and road traffic data, etc.) that contain optional social elements (i.e. sharing and collaborating via social media platforms such as

FourSquare[1] or Facebook[2]). AR technologies are today popularly used to provide field and in-situ context-aware services because of information visualization, user interaction, technological infrastructure connectivity and (location and device) sensor data fusion capabilities. Applications include personalized advertising or marketing, information on local events, remote collaborations, guidance through unfamiliar locations, and for entertainment, all of which interactions between people, technology and the environment enable learning (FitzGerald, 2012). User interactions with interfaces for AR have however fundamentally changed over the years with the advancements in AR and mobile technologies that have led to differences in form factors (Figure 4) and new affordances of mobile AR systems (Figure 5).

1.1.1 Knowledge-based Augmented Reality

A well designed presentation makes it possible for users to experience a nonexistent world or one that exists in another time or place, but designing AR information presentations requires significant skill and time because increasing the richness and variety of the information that a system is able to present also increases the difficulty of presenting it well (Feiner, MacIntyre, and Sellgman, 1993). It requires coordinated design of material that invokes featured sensory modalities that must continuously respond to user interactions, both implicitly and explicitly (MacIntyre, Bolter, Moreno, and Hannigan, 2001), i.e. providing vibrations whenever the device is pointed at the "right" direction towards the next navigation waypoint in outdoor environments. In knowledge-based AR systems, virtual worlds are created to

[1] http://www.foursquare.com
[2] http://www.facebook.com

overlay and complement the user's view of the real world that dynamically takes into account information on the user, task and changes in the real world. Following this track, Feiner et al. (1993) proposed the use of "designed illustrations" as a (graphical) design component to support the intended communicative goals of information that is supplemented to users in an AR system and is meant for aiding task-solving in real-world 3D space (Figure 6). This will be described in fuller detail in the next chapter (Section 2.2.4). In building game and AR interfaces for use in physical environments, there is also a growing design space for prototyping physical props and attachments for devices in order to communicate and aid user interactions and enrich experiences, i.e. Sueda, Gu, Kitazawa, and Duh 's (2011) work in Figure 7.

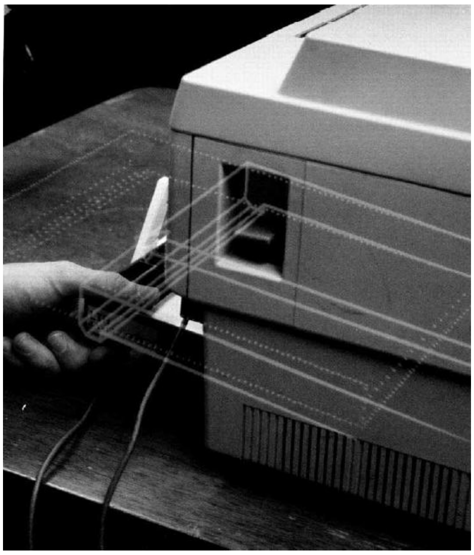


Figure 6. Overlaid graphics intended to display the action of tray pulling and resultant tray state.
(Source: Feiner, MacIntyre, and Sellgman, 1993.)

Figure 7. Semantic loupe metaphor-based browsing operations with physical mobile attachments and paper media.
(Source: Sueda, Gu, Kitazawa, and Duh, 2011.)

Figure 8. A computer vision-based handheld augmented reality game where a physical marker is required to be in view of the device's camera.
(Source: Mulloni and Wagner, 2010.)

1.2 Games

Digital games as a form of media are remarkably able to present immersive experiences to users for both digital game and non-game systems (Linder and Ju, 2012). Embodied game experiences that players have are influenced by game mechanics, the rule-based conditions for designed events (Xu et al., 2011; Montola, Stenros, and Waern, 2009) and can be used as designed tasks in such systems for player engagement (Dickey, 2005). The process of playing through a videogame's rule-based structure (either through direct simulation or through abstract representations) bears bigger impact over written, audio and visual content (Bogost, 2007). Latter elements should support this structure, but are insufficient by themselves to be persuasive to create influence and behavior change (Consolvo, McDonald, and Landay, 2009). Strategies for engagement include player positioning or “point of view”, narrative arc, and interactive choice (Dickey, 2005).

1.2.1 Handheld Augmented Reality for Games

AR technologies that are deployed on the “less costly, simpler and physically-lighter handheld devices” (e.g. smart phones; Mulloni and Wagner's (2010) work in Figure 8, etc.) as compared to heavier and more expensive head-mounted display systems (Figure 3) possess several advantages (Wagner, 2007; Figure 4 and 5). This include, 1) the ability to enhance game play, 2) to provide a common digital play space for players, 3) to share a sense of social and physical presence that support collaborations, 4) to exploit multi-modal device features (e.g. sound and tactile feedback) in user experiences and interface designs, and 5) to allow players to control the game by manipulating physical objects that are linked using computer vision-based AR technologies (Xu et al., 2008; Mendenhall et al., 2012; Koh et al., 2012; Billinghurst, Kato, and Poupyrev, 2001; Schmalstieg and Wagner, 2007) or by referencing real-world places that have been geo-registered with locative technologies and techniques. With the latter, a direct method could be by Global Positioning System (GPS) satellite signals while an indirect method could be by wireless or cellular signal triangulations (Magerkurth, Cheok, Mandryk, and Nilsen, 2005; Hazas, Scott, and Krumm, 2004).

Handheld AR (HAR) is an attractive platform for games because the new media leverages on the creative incorporations of technological device traits with behavioral user contexts in the virtual or real world to create fun, suspenseful or novel user experiences. The current form factors of consumer handheld devices ensure convenient portability and near-continuous access to these devices with much lower ownership costs than predecessor mobile AR systems (Mulloni and Wagner, 2010). It is hence important to realize how the applied technologies are relevant to, or affect the fundamental processes of designing AR gaming experiences (Chang et al., 2011).

1.2.2 Games and Real-World Activities

Game controls and interactions in digital games are opportunities to connect with our real-life values and goals. Readily allowing the disclosure or social sharing of personal information such as photos, shopping habits and revealing one's current location are just some of the activities that some people do on a regular basis today as part of their gaming activities to experience interactions that are capable of happening at a particular location at certain times (FitzGerald, 2012). As a result, the construction of this crossover of activity from virtual worlds into people's lives enables digital games to be platforms for increasing awareness and connecting to meaningful and relevant themes (Linder and Ju, 2012) known as "contexts" (FitzGerald, 2012). Apart from being used in games for entertainment, real-world activities can also be incorporated into digital game systems to complement both formal and informal, domain-centric and contextual activities and tasks (Feiner et al., 1993). These activities can adopt popular pervasive game genres as such serious (Deterding, Sicart, Nacke, O'Hara, and Dixon, 2011) or casual gaming

(Chang et al., 2011) on handheld devices (Montola et al., 2009) that can be experienced in public places (Grubert, Morrison, Munz, and Reitmayr, 2012).

1.3 Co-Creativity Processes in New Media Research

1.3.1 The Practice

There is a fundamental difference in the creation of art for "new media" as compared to older or traditional forms of (visual) art as it requires a collaborative infrastructure to produce and regularly involves (in academia) a network of artists (designers), technologies, research collaborators, funding institutions, curators and exhibiting venues/structures (Jones, 2011). Ahmed (2012) termed this as "software-dependent artwork" which interdisciplinary projects offer as co-creation opportunities for software developers and artists or designers to work closely together.

The notion of artists and technologists working together is however not new (Ahmed, 2012; Edmonds and Leggett, 2010; Wolford, et al., 2010) even in the Augmented Reality (AR) technology space (Papagiannis, 2011) and empirical models to scientifically exemplify the co-creativity processes that exist between such relationships have been previously proposed, i.e. for mixed media (Candy and Edmonds, 2002), and interactive art (Edmonds and Candy, 2010). Technology researchers when working with collaborating artists tend to attribute that artists would consider their (artists') own participation to be a form of "practice-based research" (Rust, Mottram and Till, 2007; Woolford, Blackwell, Norman, and Chevalier, 2010), one that is often heavily influenced by Schön's "reflective" concept of the self (Schön, 1983), according to Edmonds and Leggett, (2010). Artists on the other hand, when seeing technology as an artistic medium, draw creative ideas by using an in-depth knowledge of how technologies operate through experimentations (Papagiannis, 2011).

1.3.2 Maintaining an Equilibrium

Apart from the promised synergies of innovations that such interplaying arrangements are said to bring, “sparks” (friction) may also occur in artist-technologist collaborations (Meyer, Staples, Minneman, Naimark, and Glassner, 1998) and not function smoothly due to one or many of the following reasons: **1)** diverse disciplines of participating collaborators, **2)** inexplicit system specifications in artwork requirements that are subject to changes even during late stages of a project, and **3)** collaborations between artists and technologists are often driven by creativity and innovation rather than by a specific functional purpose (Ahmed, 2012), etc. In a review of practice-led research, Rust et al. (2007) identified that possible barriers of languages may exist between academics and practitioners. A bottom line thus lies in the relationships between individuals, ideas, actions and productions as “communication” (bearing a feedback-loop structure of continuous “form and re-form” according to Jones, 2011), and “mediation” (Meyer et al., 1998) processes of individual participants during an actual collaboration that is assimilated over various periods of time and within diverse socio-political situations (Jones, 2011; Candy and Edmonds, 2002).

In the view that theory and practice can each lead to developments of the other (Edmonds and Candy, 2010), a collaboration process that forces us to reposition our thinking can lead to new insights (creative and novel uses) for arts in the technology space (Woolford et al., 2010), produce positive outcomes of integrated cross-disciplined knowledge (Edmonds, and Leggett, 2010), and identifies requirements for support environments (Jones, 2011; Candy and Edmonds, 2002). It is held in the common belief by the stakeholders involved (collaborators from different backgrounds) that **access**, **knowledge** and **understanding** of the capacities of the technology and its associated constraints (direct and indirect implications) will allow the creative exploitations of technology in envisioned novel applications and approaches (Koh, Duh, and Gu, 2010), the development of new aesthetics (Papagiannis, 2011) and conventions (Chang et al., 2011; Barba, MacIntyre, and Mynatt, 2012; Gaver, 1991) beyond traditional forms (Papagiannis, 2011).

1.3.3 Creative Apprenticeships

The involvement of practitioners and students of creative arts through varying degrees, purposes and goals in technology-oriented initiatives can be seen or described as related work in the following literature: using evolving AR technology (fiducial markers) as an artistic and aesthetic medium of self-expression (Papagiannis, 2011), building an AR-painting interface to support a specific art style (Duh, Chen, Su, and Koh, 2009), teaching design through the development of an AR game (Bidwell and Holdsworth, 2006), practical production management skill training (Jones, 2011), and structuring higher education (PhDs) (Rust et al., 2007), etc. Practical training from real-world projects has been increasingly included in academic curriculum (Section 6.2.1; Rust et al., 2007). In an “artist-student” collaboration (where an arts practitioner works with a technical developer-student), the biggest risk in having student effort apart from professional efficiency and inexperience is not knowing if the project would deliver a working system or not, resulting in an entrenching sense of insecurity (Ahmed, 2012). The author of this thesis liken to think the same of the exact opposite collaboration style, a "technologist-student" arrangement where end outcomes as creative design executions of technology(ies) bears the same perceived risk and consequence of being unworkable and thus produce the very same negative disposition of uncertainty.

In this thesis, "game design" (Duke, 1980) is seen as an art form so the assertions and descriptions that have been detailed so far about artist-technologist collaborations are said to be also applicable to the discipline as well. In games, contexts may significantly inspire or affect art directions, design decisions and elements in practice-led design processes (Koh, Duh, Chen, and Wong, 2012). In AR games, this influence extends to crafted "cross-media" experience designs for user interfaces (Koh et al., 2010), designs for physical interactions (Mendenhall et al., 2012), as well as how designers may work in this particular design space; firstly with HAR games as a new media design medium and secondly, when they work with other non-designers participating in interdisciplinary research collaboration settings, i.e. extrapolating theoretical or knowledge-based needs, requirements and design approaches into detailed practical project specifications (Study 3). Media forms are sets of conventions and design elements that can be used to create meaningful experiences for target users (MacIntyre et al., 2001).

1.4 Impact of Technology Dependency of AR on Design

Understanding the limitations of featured technologies in the smart phone ecosystem is one element of thinking about their capabilities (Barba et al., 2012) and affordances (Norman, 2002; Gaver, 1999). AR being heavily technology-dependent, encounter design issues that interrupt or break the game flows that are experienced that are caused by uncertain or irregular technical performances of supporting technologies (Koh et al., 2010) in the smartphone ecosystem such as fluctuating mobile signals or inaccurate GPS sensor readings of the users' physical locations (Chang et al., 2011). The performance irregularities from these few examples are widely known to disrupt "location-based" (Section 2.1.3) gaming experiences, a popular implementation of AR technology as outdoor situated experiences (Magerkurth, Cheok, Mandryk, and Nilsen, 2005; Wither et al., 2010).

Studies in AR did not draw explicit attention on its design and conceptualization processes of such media from a viewpoint of possibly exploiting the inherent characteristics of embedded and ambient technologies (limitations in particular) to impact the contextual designs of game activities or tasks (Linder and Ju, 2012), narratives, game mechanics, user-to-user and user-to-system interactions, interfaces, and experiences (Chang et al., 2011; Xu et al., 2011; Koh et al., 2010), and secondly on the design experiences and outcomes resulting from co-creativity processes between designers, artists and collaborators (Koh et al., 2012; Edmonds and Candy, 2010). Literature is also lacking for exploring the connections and differences between physical interfaces, game design, and design methodologies that foster their integration

(Mendenhall et al., 2012) and evaluations (de Sá and Churchill, 2012). For a designer to properly work with AR as a medium, the challenge today is to understand the capabilities of what these embedded technologies may empower, rather than what they individually are (Barba et al., 2012).

1.5 Motivation and Scope of Research

The fundamental gap for designers to work in the design space of domain-centric AR game media is therefore collectively manifested as missing design methodologies, rationales and guidelines to fuse firstly, traits of evolving new media and related supporting technologies, and secondly, a selected knowledge domain (grounded on its operationalizing theory) into specific knowledge-based design components (such as game structures, activities, user interface and interactions, etc). This gap may be partially attributed to the highly interdisciplinary nature of AR that typically requires an initial understanding of issues and jargons in other domains such as Computer Science, Engineering, and Social Sciences, which sometimes poses as an early entry barrier for designers. There is also little work that discusses the co-creativity issues and roles between designers and collaborators in increasingly common interdisciplinary settings in real-world research or developmental environments for AR game projects.

1.6 Aims and Objectives

The ability to blend and adapt information on an activity and practical basis, and then to represent it with compatible technologies on hand to aid users accomplish their goals, are critical skills for designers and researchers alike in the design of AR experiences (Barba et al., 2012). This thesis is an explorative research that aims to inform designers with a HAR game design methodology (the "contribution") that has been established based on initial empirical evidence, insights and design experiences from the three interlinked studies that have been conducted (review-, quantitative-, and qualitative-based). As the contribution of this thesis, a conceptual game design framework and a game design model are proposed to aid designers in working with collaborators in this design space. Application strategies and guidelines are presented for the proposed game design framework and model respectively.

1.7 Approach and Outline of Thesis

Research is an inquest into knowledge creation along a journey of learning. Mason (2002) believes that the "discipline of noticing" is crucial to the work of researching one's own practice. This research mainly draws from fundamental theories and research in the areas of Computer Science (Human Computer Interaction), Social Sciences (Communication and Education), Design (Game Design, Practice-based Research and Interdisciplinary Research), but seeks to closely relate to (non-technical) designers with backgrounds in digital design, industrial design, visual design and user interface/experience design through the many insights that are shared.

This multi-part thesis employs "research through design" (Zimmerman, Forlizzi, and Evenson, 2007) as the main research method and reflects on the various design processes of HAR game media largely from initial theoretical conceptualization, practical implementation and evaluation phases.

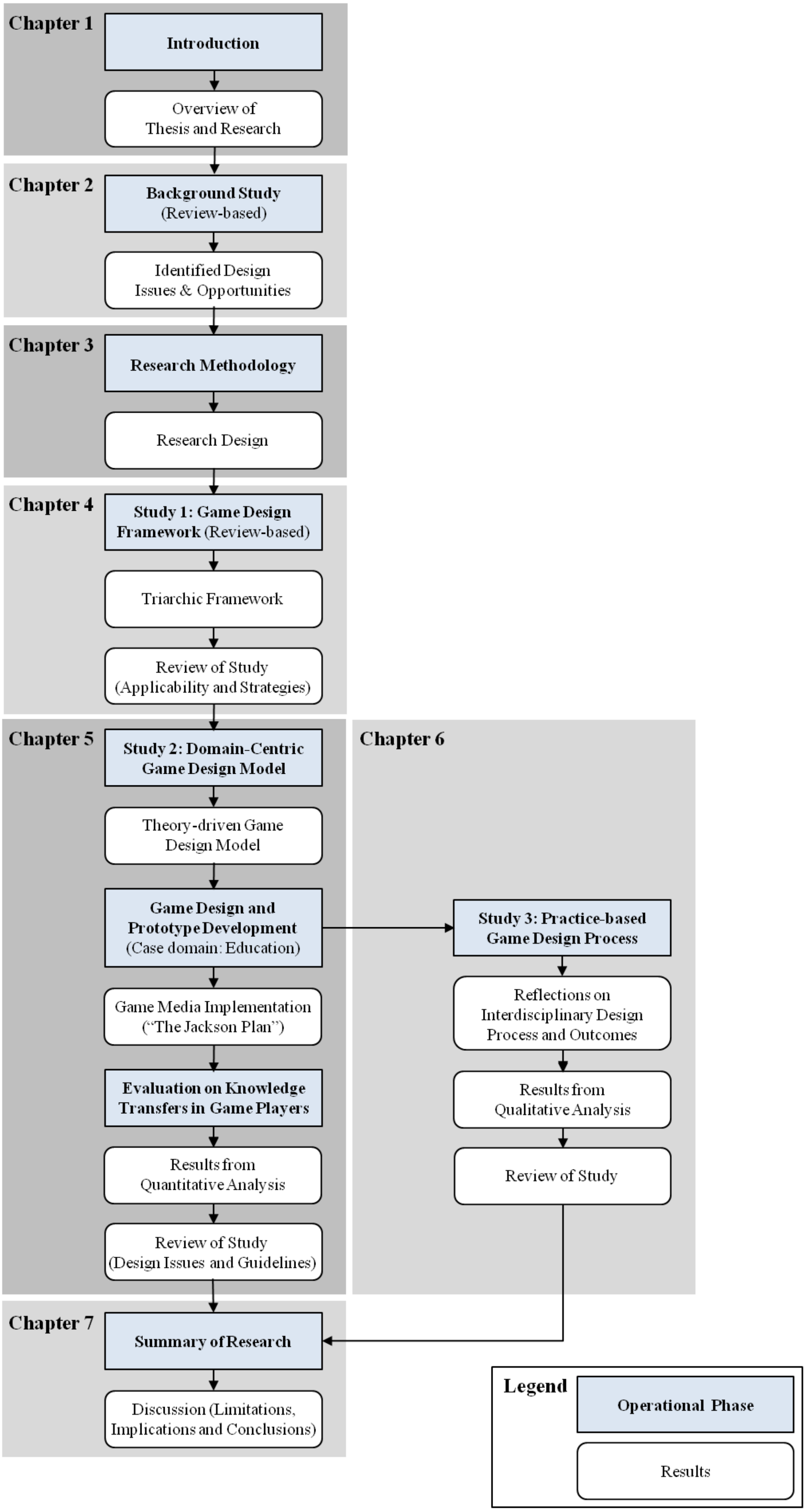


Figure 9. Overall structure of research.

The overall structure of this research (Figure 9) is presented as follows:

Chapter 2 - An additional in-depth literature review on HAR, games, and their design in order to introduce commonly discussed issues and design themes.

Chapter 3 - This chapter describes a synopsis of the methodological approaches, experimental design or analytic methods that are used in each of the three enclosed studies.

Chapter 4 - The first study is review-based and looks at game literature to identify the game elements that are designed based on, or around, the definitive advantages and/or limitations of HAR as a form of pervasive technology that may affect game play experiences. A theoretical design framework to elicit an interplaying triarchic and coherent relationship between fundamental system, application and interaction levels of considerations is introduced.

Chapter 5 - The second study introduces a game design model for structuring theory-based requisites from a selected knowledge domain into HAR game design. The domain of "Education" is used as an illustrative case for this study. Based on the proposed model, the design, implementation and evaluation experiences of an outdoor location-based handheld game prototype for situated history learning are described as a case for translating theoretical educational themes (domain-centric communicative goals) into knowledge-based game and interaction design components. The quantitative evaluation on learning performance by student players in the user study shows that the communicated goals of the integrated knowledge-based components designed in the game media have been met (i.e. through the application of communicated knowledge by formal assessment).

Chapter 6 - The third study focuses on implementation issues when the theoretical model (Chapter 5.2.1) is applied in practice by reflecting on the practice-led generative design (Bidwell and Holdsworth, 2006) transpirations of a work arrangement with two creative arts students, both as “full” practitioners in 2D art and game design developments respectively. The design students worked in an interdisciplinary collaborative environment with three researchers from technical (technology), design and social science (education) backgrounds. The aim was to co-develop the outdoor location-based game prototype for **Study 2** (Chapter 5) during the students’ 6-week internship. Empirical observations based on the project's co-creativity roles, design outcomes and qualitative interviews with the student-artists revealed media design practice and collaboration issues from this interdisciplinary experience in a real AR game development process based on the game model. The practice-led study relates how a clearer understanding of such didactic situations can realistically empower and invoke co-evolutions of both art and technology in AR as a new media.

Chapter 7 - This thesis is concluded with a discussion on the implications of the three studies that have been conducted with some possible directions for future work.

Chapter 2. Literature Review

2.1 Games

2.1.1 Game Design

Games are systems of experience and pleasure; of meaning and narrative play; and of simulation and social play (Xu et al., 2008). Game design is a process in which a designer creates a game to be encountered by players. The purpose of the design is to engage players (Dickey, 2005). Play emerges as a result and interaction occurs between players, game mechanics and challenges. Game design is at the forefront of cultivating innovative techniques for interaction design. An approach in game design is in the consideration of playability that is provided through the important game elements that constitute a game experience. Traditional game design (Bates, 2004) generally focuses on design issues that are related to game characters, narrative structures, game mechanics, challenges, user interface and game-player interactions, rather than on the aspects of technology that may impact the game experience (Dixon, Mitchell, and Harker, 2004). In a study by Cox, Cairns, Shah, and Carroll (2012), it has been found that simply increasing the physical demands of the game by requiring gamers to interact more with the game does not result in increased immersion. That study also investigated and concluded that time pressure make games more physically and cognitively challenging.

2.1.2 Pervasive Games

Pervasive games combine cultures, mobile technologies, network communications, fiction and arts that allow gaming experiences with temporal, spatial and social interactions. Montola et al. (2009) analyzed and divided pervasive games into eight constructed genres. These genres are not discovered but are constructed. They are not formal categories as they are loosely based on properties, historical developments, and gameplay activity that they create. These classifications of conducting play are however not all encompassing, as some games do not fit into any category while others fit into more than one, as briefly described as follow:

2.1.2.1 Established Genres

These styles of play come from long traditions and depend on established conventions as blueprints for technology-enhanced games:

Treasure hunts are the oldest genre of pervasive games where players attempt to locate certain objects in an unlimited game space. The discovery is a reward in itself.

Assassination games refer to a strongly established hide-and-seek-like game where a hunter who knows everything about his victim attempts to make the kill. The victim who does not know who the hunter is, must locate and defeat him.

Pervasive live-action role playing games (LARPs) utilize live-action role-playing techniques in physical theater-style character gameplays that are set in dedicated physical gaming environments or stages.

Alternate reality games layer everyday activities and events into game narratives to convey meaning, depth and interaction upon the real world. Fictional narrative contents constantly intersect with rapid and loose actuality in interactive experiences.

2.1.2.2 Emerging Genres

Being less recognized than the established genres, these genres are more clear-cut as there is less influence of cultural variation, but are more feature-oriented:

Smart street sports are usually technology dependent as they may involve movements of all players in the physical space as supported by locative technologies, or combine physical gameplay with a virtual one. They demand both physical exercise and cold tactical thinking and such competitive games are typically played in urban areas or university campuses. An example is the "Human PacMan" by Cheok et al. (2004).

Playful public performances are similar to smart street sports as both contain an athletic component, are usually played in places with *bystanders* and contain a performative element. These games are however inclined to create fun through performing, playing and creating a spectacle instead of relying on competition and exercise.

Urban adventure games combine stories and puzzles with city spaces by bringing the player to physical sites using locative technologies with some historical or cultural significance to explore, solve puzzles and follow structured stories while learning about history. Early PC adventure games (Ju and Wagner, 1997) heavily inspire this sub-genre. An example is "REXplorer" by Ballagas, Kuntze, and Walz (2008).

Reality games are staged pervasive events that consciously play with the concepts of real and reality to affect the urban environment in an obvious manner to bystanders. They share strong links with performance art and public space movements and can be played without players (i.e. only with unaware participants).

2.1.3 Location-Based Games

“Pervasive games” (Section 2.1.2) or “location-based games” (LBG) utilize the player's location (and possibly also other players') and space in the physical world to control some aspect of game play (Linder and Ju, 2012). This is achieved by using direct or indirect tracking technologies and methods (refer to Section 2.2.5). Physical and virtual interaction spaces mix as a result as a single hybrid space for game experiences.

2.1.4 Serious Games

Serious games typically refer to games that are designed to convey a lesson or message on a real-world topic which are mostly used for purposes other than entertainment, i.e. education, job training, health care etc. (Linder and Ju, 2012).

2.1.5 Gamification

Gamification (Deterding et al., 2011) is an emerging trend whereby day-to-day tasks are enhanced through the applications of game mechanics (rules or conditions) in a manner that introduces an element of fun into otherwise dull and repetitive activities (Linder and Ju, 2012). An example of gamification is to award game points for choosing food options with lower fat or salt content as part of improving one's diet.

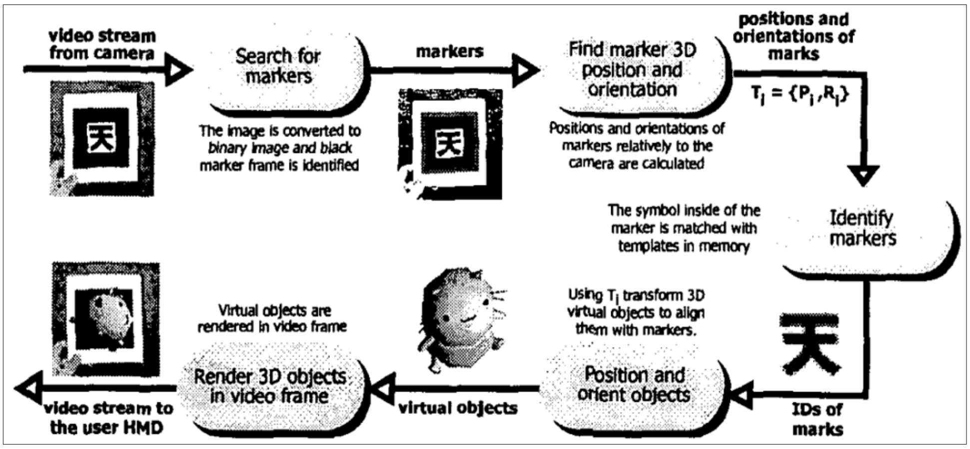


Figure 10. Computer vision-based augmented reality using a fiducial marker. (Source: Billinghurst, Poupyrev, Kato, and May, 2000)

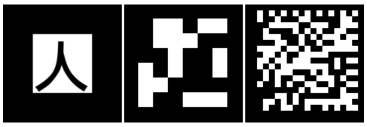


Figure 11. 2D marker types (from left): Template, ID and Datamatrix. (Source: Schmalstieg and Wagner, 2007)

2.2 Augmented Reality

In traditional computer vision-based AR, the core technology areas needed to deliver an AR application are, registration, tracking, calibration, interaction, AR applications and display techniques (Zhou, Duh, and Billinghurst, 2008), as illustrated by Billinghurst, Poupyrev, Kato, and May's (2000) diagram in Figure 10. A square black and white fiducial marker (see Figure 11 by Schmalstieg and Wagner (2007) is typically used and multiple markers may be included in a single application depending on the application’s requirements. Detailed descriptions of the technical processes and performance-related differences between the marker types can be found in the study by Schmalstieg and Wagner (2007). More recently, “natural features” are used for tracking instead of the square fiducial types by AR libraries such as “Qualcomm Vuforia” (“Developing with Vurofia”, n.d.) (Figure 12) or “metaio SDK”[3]. These visual markers appear to be any regular images or photographs, making them more appealing for designing personalized AR applications and services. In recent years, this approach has gained some popularity as mobile AR experiences by the advertising industry (Figure 13).

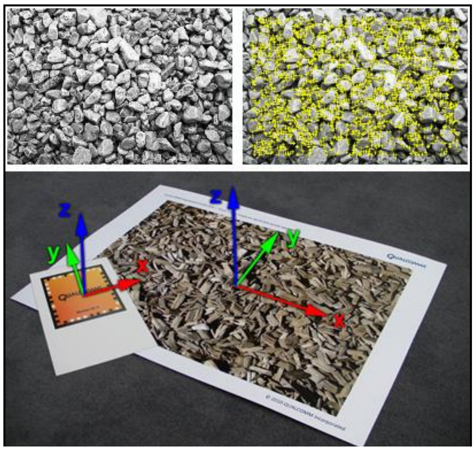


Figure 12. Photographic images registered for augmented reality natural feature tracking (Top Right: Registered visual features are in yellow, Bottom: 3D planes can be attached to support virtual augmentations). (Source: “Developing with Vuforia”, n.d.)

Figure 13. Printed magazine pages and product packages being popularly used as “markers” to trigger augmented reality experiences. (Source: “Developing with Vuforia”, n.d.)

[3] http://www.metaio.com (Last retrieved: 1st November 2012.)

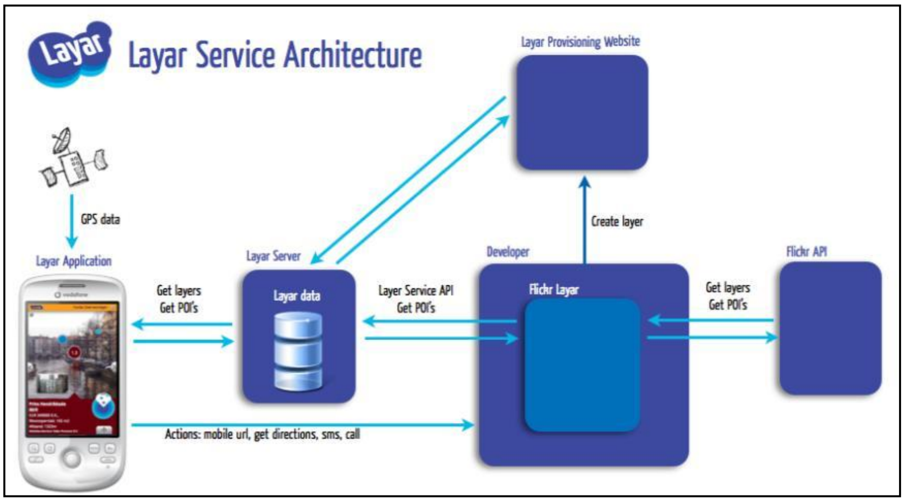


Figure 14. Top: Browser-based augmented reality combines location-sensing (GPS) and geographical "points of interests" (POIs) to deliver the user experience. Bottom: Users see a spatial representation of POIs through the mobile phone's camera view. (Source: "What is layar?," n.d.)

Another approach, the browser-based form of AR, combines the location-sensing (typically using GPS) capability of mobile phones with specific geographical "points of interests" (POIs) that are of contextual interest to users to present information access and social sharing opportunities (Figure 14). Hybrid systems utilize both computer vision and browser-based AR approaches for information representations. With either approach, users immersed and situated in the physical space being augmented render personal AR systems inherently interactive even when the content is not. This is because the user implicitly interacts with physical spaces, i.e. through physical exploratory navigations (MacIntyre et al., 2001).

Due to technological limitations of both approaches (i.e. difficulty to use 2D markers under low lighting conditions, relatively low accuracy of embedded cheap sensors in handheld devices such as GPS, etc.), alignments of physical and virtual information are still error prone or at times inaccurate in mobile AR (Barba et al., 2012).

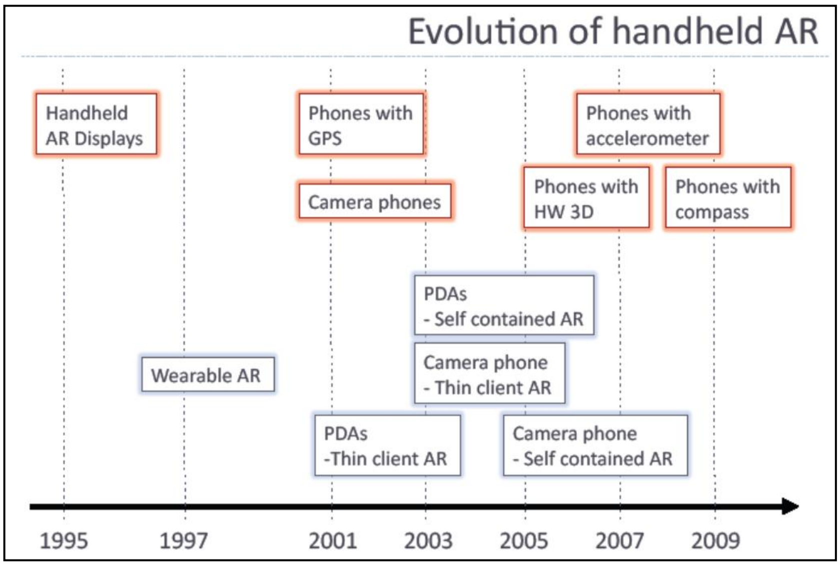


Figure 15. Evolution of handheld augmented reality. (Source: Wagner, 2007)

2.2.1 Handheld Augmented Reality

In this thesis, the definition of "handheld devices" includes digital dictionaries, Personal Digital Assistants (PDAs), mobile phones, cameras, tablets (eg. Apple iPad2), portable game consoles (i.e. Sony PSP[4] or Nintendo DS[5]), portable projection systems, and portable media players. Handheld devices as AR platforms are considered minimally intrusive, socially acceptable, readily available and highly mobile (Zhou et al., 2008). AR

[4] http://us.playstation.com/psp (Last retrieved: 1st November 2012.)
[5] http://www.nintendo.com/ds (Last retrieved: 1st November 2012.)

applications on handheld devices are supported by a wide, growing and increasingly powerful range of embedded hardware and sensory features (Figures 15 and 16) (i.e. dedicated GPU, multi-core CPU, touch-screen, compass, high-bandwidth mobile data connections (4G, LTE, Wi-Fi, WiMax), projection capability, GPS positioning, high-resolution front/rear cameras, accelerometer, Near Field Communication, etc.) that complement innovative user experiences (Koh et al., 2010). It is useful to be mindful that many of these devices are not explicitly designed to deliver AR experiences and therefore might not meet user expectations on technical performances or some incapacities may end up as technological "seams" in design (refer to Section 2.2.6).

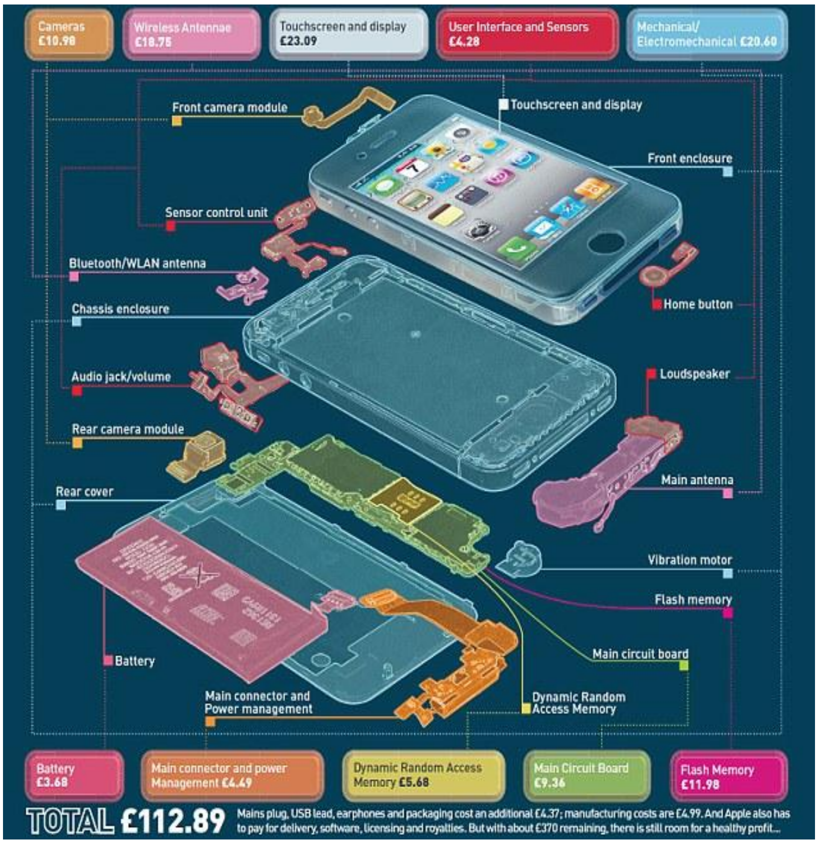


Figure 16. Rich multi-modal features of a consumer smart phone.
(Source: "Apple's iPhone 4S price", 2011)

2.2.2 Handheld Augmented Reality Games

From year 2000 onwards, the extensive use of personal handheld mobile devices has opened up new avenues of use for AR applications including games (e.g. Sony's EyePet[6]). From a technical context, an HAR game application usually consists of four key components as, 1) AR library, 2) graphics and multimedia, 3) networking and 4) a game application framework (Wagner, Schmalstieg, and Billinghurst, 2006).

AR library - The AR library performs low-level work to “talk” to the device's operating system and access low-level “Application Programming Interface”[7] (API) calls to obtain raw video data from the device’s camera stream. This allows image processing tasks and to feature point tracking to be performed (refer to Figure 10). This is an essential component for almost every computer vision-based HAR (game) application. For research purposes, two computer vision-based AR libraries are used in many early HAR and game projects, “ARToolKit” by Kato and Billinghurst (1999) (which is available for various handheld platforms including mobile phones (Henrysson, Billinghurst, and Ollila, 2005) and PDA devices (Wagner and Schmalstieg, 2003), and “Studierstube ES”[8] (Wagner , 2007).

Graphics and multimedia - The graphics and multimedia functionalities include 2D/3D scene rendering, sound engine, sensor readings, multi-touch support, etc. The performance of 3D scene and object processing

---

[6] http://uk.playstation.com/psp/games/detail/item285325/EyePet
(Last retrieved: 1st November 2012.)

[7] An “Application Programming Interface” (API) is a protocol that defines reusable building blocks (in software programming) that can be used as modular pieces of functionality to be incorporated into end-user applications (Reddy, 2011).

[8] http://studierstube.icg.tugraz.at/handheld_ar/stbes.php (Last retrieved: 1st November 2012.)

is a vital factor that affects a HAR game. This processing is more demanding than what is typically required for a handheld game and consumes much of the available processing power, making it a challenge when implementing high level components. Optimizations of AR performance on the handheld platforms thus remain as a significant area of research. As handheld devices gradually feature a wider range of integrated sensors such as compass, interactive projections, high-resolution camera, GPS, accelerometer and Near Field Communication[9] (NFC) technologies, these additional supplements can bring about new AR game experiences to users based on contexts.

Network communication - Referring to digitally mediated communication (Montola et al., 2009), it is an essential feature for a complete HAR experience in collaborative, cooperative or competitive gameplays. It can consist of two devices that use either a Wi-Fi or Bluetooth connection for the game to be played, one device acts as the server and the other as a client, or in the case of a direct server connection by a single device, a client-server architecture may be used instead on any available wireless or mobile connectivity options (i.e. Wi-Fi/4G/LTE/WiMax/GPRS/GSM) for the player to interact with other players such as in multiplayer online games or to access a remote server. Peer-to-Peer (P2P) distributed application architecture for user-sharing of tasks and resources, is commonly used in HAR games for integrating social gaming features (Xu et al, 2009; Huynh, Raveendran, Xu, Spreen, and MacIntyre, 2009). Network communication also allows access to external data and services (i.e., weather, traffic and social media, etc.).

[9] http://spectrum.ieee.org/telecom/wireless/no-more-waiting-on-near-field-communication (Last retrieved: 1st November 2012.)

Game application framework - A game application framework includes a variety of functionalities and features that can be used to build game structures, support interaction styles, and establish or guide player behaviors (Salen and Zimmerman, 2004). It is heavily dependent on the game's context(s).

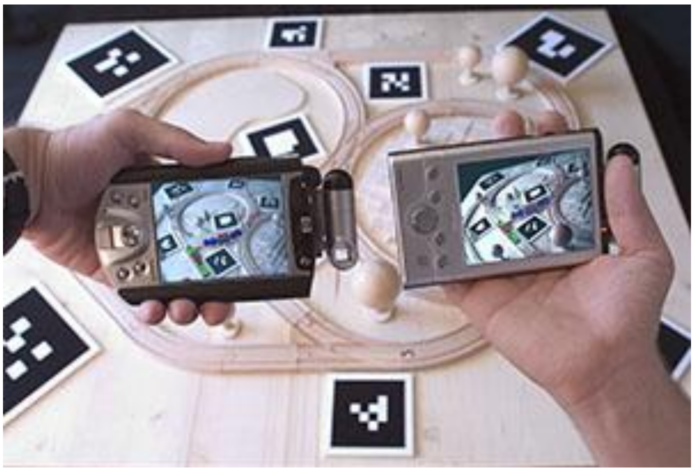


Figure 17. A multi-player handheld augmented reality game that utilizes game props. (Source: Wagner et al., 2005)

"The Invisible Train" (Figure 17) by Wagner et al. (2005) is an example of a typical HAR game that utilizes or exploits specific characteristics of AR technologies in its game design and mechanics. The goal of this game is to steer a virtual train over a real wooden railroad track with other players in a cooperative or competitive mode. A combination of AR library, graphics and multimedia functionality implementations allows players to enjoy a multi-sensory experience as if they are interacting with real objects. The experience is further enhanced through player-interactions via information exchanges using network support via Wi-Fi. This game appropriately takes collective advantage of the specific applied technologies so that players can be closer involved in the game flow through the intuitive supporting mechanisms.

2.2.3 Handheld Augmented Reality Game Design

Understanding certain characteristics of technologies is fundamental to create a good user experience. In the discussion in Thomas's (2012) study, HAR games can be coupled with common technological features in their design, including the combination of physical and virtual spaces to create engaging real-time interaction opportunities that are triggered on “correct cue placements”. Exploiting the limited field of view of the user in an encapsulated world, establishing full-body visual cueing mechanisms and physicality of moving in open spaces are appealing features of AR that support novel gaming. Deciding on whether a game is played indoors or outdoors (and where) is a crucial initial element of design. More HAR game examples can be found in that study.

2.2.4 Knowledge-based Design

Feiner, MacIntyre, and Seligmann (1993) proposed the use of a “knowledge-based graphics component” that utilized the rule-based “Intent-Based Illustration System” (IBIS) by Seligmann and Feiner (1991) to dynamically present designed illustrations to users in a task-solving AR system. IBIS helps to satisfy the input communicative intent that is specified by a prioritized list of communicative goals of the real or virtual intended representations to be depicted. This is achieved by using design (a high-level structure that indicates the particular visual effects that must be accomplished to satisfy an illustration's communicative goals) and style (various approaches on how each visual effect can be accomplished) in an illustration (Feiner et al, 1993). Each communicative goal specifies something that a designed illustration is set to accomplish and IBIS originally provided communicative goals along with representations of the physical objects that are to be depicted.

Two rules are employed in IBIS: methods and evaluators. Methods specify how a particular design or style may be accomplished, while evaluators determine whether a particular design or style has been accomplished. The rule base is organized such that communicative goals are achieved by design rules that decompose communicative goals into a lower-level set of goals called “style strategies”. A design rule uses a design method to accomplish a communication goal by invoking a set of style strategies and design evaluators. The success of a communicative goal is evaluated by the success of a set of style strategies.

2.2.5 Locations and Spaces as Loci of Contexts

Locations can be key or part of a choreographed playing experience. Videogames are able to use them as space in two ways, one as a rhetorical means of expression and two as forms of spatial aesthetics. These are done through representation (communication of messages and ideas) and embodiment (the player is encouraged to take up a particular position in relation to the game), as Martin's (2011) PhD dissertation has explored. Representation and embodiment feed back into each other and combine to set up the experiences available to the player during the game. Their considerations, associations and interpretations synthesize a game's core theme into the player's experience and they are affected by conventions of game genre (discussed in Section 2.1.2) which in turn affect the contexts of game production such as level designs for situated play experiences in imaginative 3D worlds (Milam and Nasr, 2010).

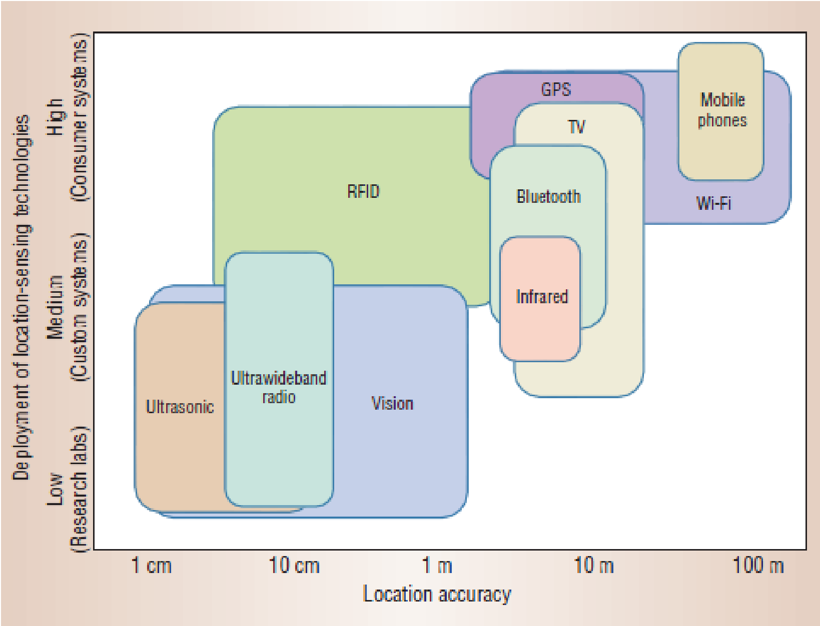


Figure 18. Location accuracies of deployed sensing technologies. (Source: Hazas, Scott and Krumm, 2004)

Location as a critical component of context is an important underlying theme of current location-based AR applications (Barba et al., 2012). Many of the satisfying experiences largely arise from the exploitations of location-based features instead of only relying on the sole characteristics of AR. AR can relate and integrate digital information in tangible surroundings and environments, allowing users to access, manipulate and create location and object-based information through intuitive interactions with the physical world (Olsson and Salo, 2012). The choice of how AR is deployed is fundamentally related to how virtual content is superimposed and interacted with within physical environments (Squire et al., 2007) and how users are encapsulated in a synthetic world (Thomas, 2012). In either case, varying embedded hardware configurations and sensor data, i.e. see Hazas et al.'s (2004) diagram in Figure 18, can “collate” useful user-data, provide interaction opportunities and determine spatial context(s) or location(s) that handheld devices are being used in Wetzel, Blum, Broll, and Oppermann's (2011) work, and at times infer possible user intents. Such “insights” are useful in the design of user experiences (Koh et al., 2010). For instance, browser-based AR typically combines GPS/Wi-Fi and virtual information or sensor data overlays in camera views to support location-based services (LBS). Such use of AR has motivated the creations of hybrid spaces where places are regarded as space with meanings (Barba et al., 2012). Gaming in a hybrid space promotes engagement and supports knowledge transfer in learners. Squire and Jan's (2007) AR LBG supports learning in environmental science by combining an AR game structure with physical space. Taking the notion from the HCI domain that "A place is space with meaning", a key challenge however lies in determining what data are relevant, how to collect them, when to retrieve them, and how to represent them when users are done. These are also the elements that are needed to convert a “space” into a “place” (Barba et al., 2012).

2.2.6 Seamful Design

AR technologies (including handhelds) when based in or around physical environments exhibit various characterized differences (including the uncertainties and inaccuracies in network and tracking performances respectively) that Weiser (1994) termed as “seams” through his concept of “seamful design” (being “literally visible, effectively invisible”). Seamful design can be defined as a design approach where the internal functions of a technology are intentionally made obvious to its users, and the technology itself is a utilized design resource instead of an encumbrance. Game designers employ this approach to work around such seams to maintain the overall interaction flow between game mechanics and players, and yet retain the richness of each interaction tool.

Example 1 - Augmentation may get disrupted abruptly if a detected marker suddenly goes out of view from an active camera (i.e. in many cases, virtual content would suddenly “disappear” as soon as a detected fiducial marker is occluded by the user, or become undetectable due to improper user handling). One seamful measure would be for the designer to design a visual feedback mechanic that responds to detected loss of marker tracking (see Figure 30 and Figure 32).

Example 2 - One of the prominent characteristics of HAR games is mobility. HAR devices are almost entirely mobile, access to them may hence be non-continuous or limited because of environmental factors that the devices are being used in. Players are likely to drop in and out of games relatively quickly as a result. For example, playing a game while waiting for a bus can be disrupted when it arrives, or the loss of mobile (telecommunication) signal onboard a moving transport that is travelling through a tunnel can break established network connections for online mobile games. Casual games in this case can be a more suitable design implementation to address this seam because they are short session games that are easy to play (Bates, 2004) which can be ideal for people on the move. These games are less likely to require constant access to online services for them to be playable. The consideration and use of a seamful design approach can be factored in the associated game experience design (Figure 30) process for HAR games so that they may still be played under various restrictive environmental conditions, or bear mitigating or bridging measures to handle the technological seams that surface as a result of such sudden change(s).

2.2.7 Collaborative Augmented Reality

Collaborative AR blends the physical and virtual worlds so that real objects can be seamlessly used to interact with 3D content that would reinforce greater shared understanding (Billinghurst and Kato, 2002) and novel gaming experiences. In exploring how AR platforms can be used to enhance face-to-face collaboration, Billinghurst, Belcher, Gupta, and Kiyokawa's (2003) study found that users using a multi-user collaborative AR interface exhibited similar behaviors to that of a face-to-face unmediated collaborative condition. AR can enhance the sense of reality by using spatial cues and tangible user interface metaphors to support face-to-face collaborations in learning contexts. In Wagner et al.'s (2006) work, an HAR arts-history learning game is presented where players collaboratively pick up and place artworks into the corresponding slots on a timeline. The study shows that collaborative HAR surpasses traditional paper media in satisfaction, intensity and learning efficiency. The use of shared spaces in AR can be crafted to provide a common environment for "player-sensing" and player-to-player interaction rather than to only present a simple on-screen experience, and this is so even if players may be physically apart (Montola et al., 2009; Xu et al., 2011).

2.2.8 User Experiences of Handheld Augmented Reality

A stimulating and pleasurable user experience (UX) is often the central goal and strategy in the design of technology products and services. In games, the user experience lies in player engagement (Dickey, 2005). UX is heavily dependent on contextual factors (social setting, cultural influences and other user activities) and can be defined as a comprehensive concept that describes the subjective experience that results from the interaction with a technological product or service (FDIS, 2009). In a qualitative analysis of an online survey in a recent study by Olsson and Salo (2012) with 84 users, unsatisfactory user experiences with mobile AR applications (in extents of functionalities and usability) have been mainly associated with inadequately performing technology (i.e. hardware deficiencies) or instrumental expectations not being met. Many AR applications are impractical to use, and so many people do not (Barba et al., 2012). In many cases, this can be attributed to the lack of proper integration of services and technological capabilities (being mindful of their limitations at the same time) for weaved UX scenarios.

2.3 Education (Selected Knowledge Domain)

2.3.1 Learning Objectives

Bloom's taxonomy is a widely applied classified series of learning objectives in the cognitive domain in an order from "simple to complex", and "concrete to abstract" categories (Bloom, 1956). It serves as a common language towards learning goals to bridge communications across instructors, subject matters and grade levels and is also a basis from which educators can determine the congruence of educational objectives for a particular curriculum. It has also influenced instructional objective formulations in education (Bloom, (1956); Krathwohl, (2002)). As rising infocomm technologies (ICT) in education focuses on thinking processes, Krathwohl, Anderson, and Bloom (2001) revised the original taxonomy using a bi-dimensional approach as, 1) knowledge dimension: refers to what has been learned (as Factual, Conceptual, Procedural and Metacognitive Knowledge) and, 2) cognitive process dimension: refers to cognitive skills that can be applied to learning tasks (as Remember, Understand, Apply, Analyze, Evaluate and Create). Bloom's revised taxonomy thereafter is regarded as a functional and successful guiding tool for instructors and learners (Valcke, Wever, Zhu, and Deed, 2009). Mayer (2002) used it as a framework for specifying valid computer-based assessment items to measure problem-solving transfers on learning. The taxonomy also aligns learning objectives with instructional activities and assessment tasks. Only when clear objectives are provided can complementary tasks and instructional strategies be properly assessed and fused into the unit of curriculum (Raths, 2002). AR games extend beyond purely providing information, knowledge is instead embedded within contexts of the surroundings where learners have to organize, evaluate and navigate information structures in various locations of shaped activities. Cognition is thus materially situated across devices, contexts and physical resources. Activities that are constrained by the surroundings in turn affect learners' cognitive process by altering the way they process knowledge (Klopfer, 2008; Squire et al., 2007). The revised Bloom's six-category classification (Krathwohl et al., 2001) distinctively surfaces from the descriptions that are allocated to the specific cognitive processes, which collectively characterize the respective category's breadth and depth (Krathwohl, 2002). Through interactions, constructing knowledge involves assessing basic memory to the ability of employing various cognitive strategies.

2.3.2 Situated Cognition

Situated cognition, or situated learning theory, is a cognitive process that is based in a "community of practice" (Lave and Wenger, 1991). It inseparably involves surrounding physical and cultural settings by exploiting their relationships. Learning in situated conditions acknowledges that meaningful learning requires students to bond physical and social contexts that would allow authentic practices through activity and social interaction (Brown, Collins, and Duguid, 1989). Conceptualizing and implementing processes of situated cognition in learning settings are difficult to be applied because the supporting theory is only an ideology that establishes an initial perspective on meaningful learning and it lacks a complete framework for educational settings (Herrington and Oliver, 1995).

2.3.3 Instructional Strategy

The term “scaffolding” was first introduced by Wood, Bruner, and Ross (1976), who liken it as a metaphor of structure for cognitive growth. For technology in education, Hill and Hannafin (2001) summarized four types of scaffolding mechanisms which instructors may adopt (1) Conceptual scaffolds: to simplify complex concepts, guide learners in prioritizing or making decisions on things to be considered. In scaffolding, cognitive map or mapping tools can be used; (2) Metacognitive scaffolds: instructors provide learners with a clear and structured process to help them organize and reflect on the ways to access goals by providing prompts or problem-solving steps; (3) Procedural scaffolds: to assist learners on utilizing and accessing resources. Navigated graphs or site-maps enable learners to understand and reduce their cognitive loads; (4) Strategic scaffolds: to help learners chart plans or strategies while they are performing a task. Scaffolding stresses on a situated nature and social interaction that enables instructors to guide learners through adequate learning strategies and activities of learning content.

2.3.4 Learning with Augmented Reality Technologies

AR technologies in the field of education have demonstrated potential in helping students learn more effectively and increase knowledge retention as compared to traditional 2D desktop interfaces (Billinghurst and Dünser, 2012). Handheld devices are also compelling and useful mediums as a pervasive game platform for supporting learning activities (Montola et al., 2009).

The inherent technological attributes of a handheld platform therefore impose on interaction designs in HAR gaming concepts for education. In the education domain, the gap lies in the lack of design principles for orchestrating and integrating dependencies of instructional strategies and social interactions into overall gaming experiences and interactions for learning (Squire et al., 2007).

2.3.5 Technology and Knowledge

With change momentums in technological innovations, Dosi (1982) presented a general framework that explicates the selection process of technological paradigms among a greater set of theoretical problems. Dosi (1982) subsequently defined the concepts of "technological paradigms" and "technological trajectories". The former is defined as a model and a pattern to determine the solution(s) of a selected technological problem based on selected principles and material technologies. The latter is defined as a pattern of "problem-solving activities" using a technological paradigm. Technological trajectory (i.e. problem-solving activities) is hence asserted as a collection of possible directions whose outlines are confined by the inherent nature of the technological paradigm. The interplaying relationships between content, pedagogy and technology are complex since decisions have a ripple effect on one another (Mishra and Koehler, 2006).

2.4 Summary of Literature Review

This thesis aims to address the methodological gap in HAR game media design from a domain-centric and technological perspective. The specific aims and objectives, as well as the approach and outline of the thesis, have been introduced earlier in Sections 1.6 and 1.7 respectively. Chapter 2 provides additional theoretical grounding for this research.

A multidisciplinary literature review has been conducted to link the main related fields: **Games**, **AR** and **Education** (the case knowledge domain that has been selected to illustrate the proposed design methodology which will be introduced in later chapters).

The domain of education presents design issues and opportunities that complement the active discussion of the designed methodology that is proposed in this research. Handheld devices are compelling and useful mediums as a pervasive game platform for supporting learning activities (Montola et al., 2009). The attribute of mobility in handheld devices with an increasingly powerful array of embedded hardware and sensors in them allow AR technologies to create highly-engaging and collaborative learning experiences in physical environments in and beyond classrooms, and for educators to move beyond plain information-retrieval type pedagogies (Squire et al., 2007). In a mobile era, learners no longer follow a singular curriculum but instead are constantly "on the move with time, and applying knowledge from one space to another within the constraints of technologies" (Sharples, Taylor, and Vavoula, 2005). Locations and contexts are also often discussed for inclusion in user experience design (Billinghurst and Dünser, 2012).

Designs that are based mainly on the features of a new technology however are “often technically aesthetic but functionally awkward” (Gaver, 1991). Traditional instructional design approaches may thus be insufficient to extrapolate pedagogical selections and directions from the abilities and features that are brought forth and enabled by new technologies and the interactions that they afford for user experience design. When educational pedagogies and learning concepts have to be integrated with HAR gaming experiences, they carry design implications because there is a lack of a formal framework or a set of design principles for translating such requirements into crafted educational HAR (eHAR) gaming experiences.

The integrated overview of this design space establishes the foundation on which the research methodology is based in the next chapter.

Chapter 3. Research Methodology

3.1 Organization of this Research

This research is multi-part to elicit issues and perspectives from various levels of design of HAR game media by exemplifying and reflecting (Zimmerman et al., 2007) on the following three respective studies, where mixed methods (review-based, grounded theory, practice-led design, quantitative and qualitative analyses) have been used to gather the empirical evidence across the studies.

Chapter 4 (Study 1): Based on extensive literature review, the study first identifies the game elements that revolve around the definitive advantages and/or limitations of HAR as a form of pervasive technology that may affect game play experiences. HAR game experiences are examined and described through a proposed triarchic interplay of coherent associations comprising fundamental Application, System and Interaction levels to facilitate the formulations of early design considerations.

Chapter 5 (Study 2): Learning is one of the areas which AR technology has been widely deployed to support (Billinghurst and Dünser, 2012). Utilizing the domain of Education as a use case to draw critical insights from, the triarchic framework from Study 1 is extended through the elaboration of how a domain's core theory can be applied into the paradigm of a proposed game design model that bears four characterized educational HAR (eHAR) game types that are differentiated according to the dichotomous extents between technological availability of “location-based services” (LBS) and “user collaboration” features. Each distinct technological pair is differentiated through the highlighted and varied playing styles that can be achieved. With it, an instructional strategy that supports the selected learning theory (knowledge base) then has its mechanism(s) and approach(es) matched to categorized learning objectives in the Application level to operationalize the adopted learning theory’s ideology. Intended learning objectives are in turn drawn by educators to match an educational curriculum, and the perspectives that can be drawn using this approach (i.e. deriving the necessary relevant mechanisms, and measures to support a specific learning objective) are used to extrapolate interworking System and Interaction level elements for eHAR game design considerations. These collective revelations provide a coherent leveled ground for educators, designers and developers to work from because the described process identifies the requirements, issues and possible resolutions that are necessary for each collaborating domain. Next, the conceptualization and implementation of “The Jackson Plan” outdoor location-based game (LBG) for site-based history learning is described to elaborate how the eHAR model can be used in practice (i.e., translating learning objectives into communication goals of knowledge-based design components and design styles).

This is followed by a quantitative evaluation of the game prototype on learning performance by student players while factoring user behavior issues (motivation, learning strategies and engagement). Although this empirical evaluation of the game prototype on learning performance is not a key focus of this thesis, it validated that the communication goals (from domain knowledge) of the designed media were met. The study shows the initial translation process of theoretical and knowledge-based instruments into practice-led design components including user experiences, user interfaces, knowledge-based components and design styles, and game narrative structures.

Chapter 6 (Study 3): Real-world issues when the theoretical game model from Study 2 is executed in practice are presented in this study. A real-world case study is reported where two students who were new to AR as a design medium played the dedicated artists' roles in art and game design developments while integrating educational curricular components to meet requirements of the project's knowledge-based communication goals and design styles. The project involved staff researchers from an academic research laboratory from technical, design and social science (education) backgrounds respectively for the development of the eHAR game prototype for Study 2. This qualitative study also recognizes and reflects upon the important co-creativity roles and intimacies that arts or design students may play in increasingly interdisciplinary environments where research and design potentials of evolving (i.e. AR) new media technologies are explored.

Chapter 7: A summary of research is presented to discuss the implications of the three studies, limitations for the research and possible directions for future work.

Table 1. Design levels for handheld augmented reality games.

	Concept	Issue(s) and measure(s) (Selective references are examples of the respective measures being discussed)
1. System level	AR system	* Use of real-time overlaid 3D virtual objects in the real world. * Instill awareness of game states that are influenced by slow/inaccurate tracking traits and lighting conditions; * Slow tracking: Avoid rapid button presses (Huynh et al., 2009), sudden camera movements and intensive 3D graphics (Henrysson et al., 2005). Technical loads should be balanced (i.e. use pause intervals such as load screens) and pacing should take into account the extent of tracking performance. * Handling uncertainties / Inaccurate tracking traits: "Pessimistic" to show only information that is correct, "cautious" to intentionally show inaccuracies, "opportunistic" to exploit inaccuracies (Chalmers and MacColl, 2003). * Lighting: Set controlled parameters (use flashlights to improve lighting under dark conditions as a game scenario (Bichard and Waern, 2008).
	Network communication	* Uncertainties in wireless/co-located communication can employ game structure deliberations such as careful game location/timing selections, intentional hiding/revealing for players to adapt/exploit, incorporation into game structures (i.e. "hide in shadows" outside network coverage areas) (Benford, Magerkurth, and Ljungstrand, 2005).
	Form Factors	* Design focused activities for small screen display screens.
	Mobility	* Interruptability: Quickly resume or load the last saved game state. * Gameplay should be short (Bates, 2004). * Instill contextual adaptability (Montola et al., 2009).
2. Application level	Social Interaction (example)	* Enable social communication during game play through: Face-to-face collaborations/competitions (verbal / nonverbal communications), remote interactions for seamless unity of players. * Instill sense of social and physical presence (Xu et al., 2008).
	Learning (A knowledge domain example)	* Show virtual content in physical spaces. * Allow collaborative learning via network communication. * Quick deployablility. * Easily accessible platform. * Induce physical exploration for knowledge inquiry. * Apply Information Visualization techniques (Gu, Chen, Koh, and Duh, 2010)
	Contextual Information (environment)	*Foster explorative mobility of players during game play.
3. Interaction level	Manipulation	* Assert physical affordances of associated input devices as interaction tools (Mendenhall et al., 2012). * Enable control of virtual objects by tangible manipulation of physical attributes. * Maintain interaction flows to provide a more complete and engaging experience.
	Multi-sensory feedback	* Allow progressive task completions. * Instill awareness of technological limits via sustainable measures.

Chapter 4. Study 1: A Triarchic Conceptual Framework for Handheld Augmented Reality Games

4.1 Overview of Study

This review-based study introduces the conceptual understanding of a potential interplay between System, Application and Interaction levels that subsist in previous HAR game research, and identifies key characteristics of HAR technologies that may affect game experiences. Related work in HAR games, game design and seamful design are drawn and reviewed from literature. This is followed by an analysis on selected HAR games to describe the game elements in them for the proposed game design framework.

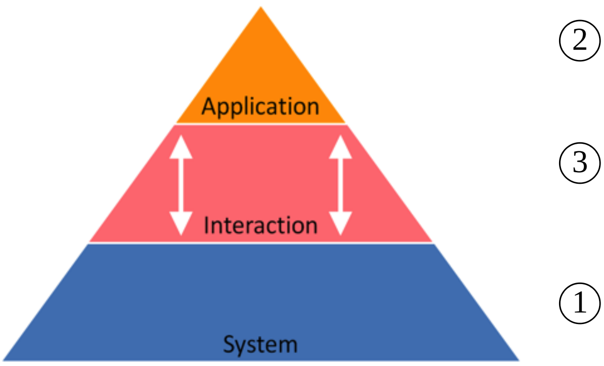


Figure 19. Triarchic conceptual design framework.

4.2 Procedures

4.2.1 Three Levels of Consideration

Centered on the issue of heterogeneity, game design for HAR games tend to specifically involve an interdependent underlying System level that coherently includes all the characteristics of the applied technologies. The next

Application level is context dependent and can be multi-varied, such as in "facilitating learning" and "enhancing social interaction" for example. Lastly, an Interaction level is extrapolated from the interworking elements of the two levels (System and Application) being associated in ascertained compatibility (Figure 19). The matching of identified elements in system and application levels firstly support appropriation(s) in varying degrees in HAR systems and secondly, fulfill the primary goal of the intended application. This matching can thus unveil interaction design level issues that should be considered and addressed in the HAR game design process. The next section presents relevant game design components from consolidated HAR game literature, followed by details on how these games have been designed with elementary aspects of game design that exploit the features or limitations of technologies as definitive attributes.

4.2.2 Literature Categorization Method

The relevant reviewed publications are distilled as representative works for each associated category of design constitutions with respect to the three levels of consideration (Section 4.2.1). Moderation is performed through the consideration of the selected publications' exploitations of the nature and characteristics of HAR technologies, rather than focusing on the inherent generic game elements in them. According to Malone (1981), games ideally must have clear goals although their outcomes may be uncertain. Thus while achieving these goals what players would encounter can be interpreted as challenges that the games provide. Through game play, the sense of pleasure and satisfaction may be increased. The use of feature-enabling technological attributes, such as utilizing physical accelerometer-tilts to provide in-game character/object rotations, can intrinsically add on to this enrichment.

4.3 Results and Discussion

In the review of the selected HAR games, several distinct characteristics of HAR technologies that are divided according to the three levels of consideration for HAR games are identified and highlighted in Table 1.

4.3.1 The System Level

4.3.1.1 Handheld Augmented Reality Systems

The fundamental level of game design is established using the features of applied technologies. The characteristics of HAR technologies that are closely related to game experiences notably include performances in tracking, lighting conditions, and network communications. In HAR systems, several prominent features may affect the overall gaming experiences. For example, interactive 3D graphics employed in the HAR games may intensify sensory immersion levels (one of the three gameplay experience models developed by Ermi and Mäyrä (2005)).

The majority of the reviewed HAR games make use of computer-vision-based tracking technologies to assist in the creations of game experiences. As an alternative to ordinary square fiducial markers, the work by Paelke, Reimann and Stichling (2004); and Park and Jung (2009, 2007), utilize natural features to aid the tracking systems.

Figure 20. Foot-based interaction on a handheld device.
(Source: Paelke, Reimann, and Stichling, 2004)

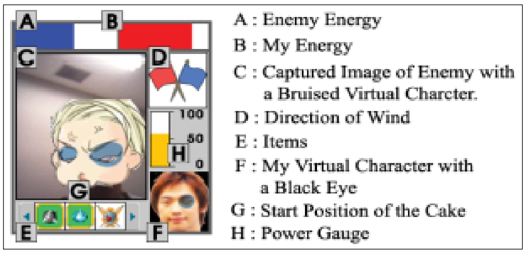
In “AR Soccer” (Paelke et al., 2004), players “kick” the virtual football from the screens of handheld devices. The game system captures foot movement and then calculates the direction and speed of the ball to complete the game interaction (Figure 20).

“Flying Cake” (Park and Jung, 2009) is similar as it also uses physical body movements that are detected by the cameras of handheld devices to provide the game experience of throwing or dodging virtual cakes. Both single-player and dual-player modes of gameplay are supported through varied system configurations (Figure 21).

“Augmented Galaga” (Park and Jung, 2007) makes use of specific objects in the actual environment as virtual enemies that players must “attack”. Feature matching (Figure 10) is automatically performed when the predefined objects come under the purview of the handheld device (PDA). As part of the game mechanics, it is intentionally and seamfully designed that players have to center and maintain the handheld device’s camera/screen on the virtual enemies (objects), or their energy levels will decrease (Figure 22).

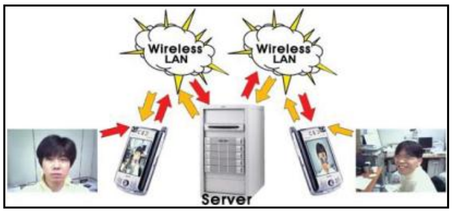
Barba, Xu, Maclntyre, and Tseng (2009) presented three games that used multiple markers to form novel game experiences (Figure 23). Virtual objects can be moved between physical markers in these games.

(a) Real-world view



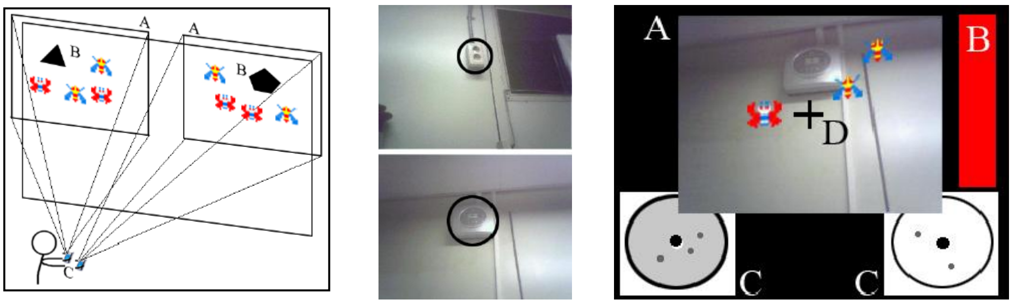
(b) Main user interface on PDA screen.

(c) Single-Player mode



(d) Dual-Player mode

Figure 21. Exploiting physical movements and computer vision-based augmented reality game on a PDA. (Source: Park and Jung, 2009)



(a) (b) (c)

Figure 22. Overlaid virtual game elements (a) Physical space is utilized. (b) Physical objects/features are marked using a stylus pen. (c) Enemies' (A, B) and Player's (C, D) attacks. (Source: Park and Jung, 2007)

Figure 23. Three games with the same physical mechanics (from left to right): "AR Puzzle Pacman", "Terrain" and "Candy Wars". (Source: Barba, Xu, MacIntrye, and Tseng, 2009)

"Seams" of HAR (discussed in Section 2.2.6) can be used as resources for game design. Since screen displays are too small to have extended graphical views, games can be designed as focused activities. Game flows and experiences that may break under unsuitable or unpredictable operating conditions (i.e. due to poor lighting, sensitive tracking and disrupted wireless communication signals, etc.) can instead feature indicative parameters for player guidance (Benford et al., 2005) as mitigation measures (i.e. visual feedback).

4.3.1.2 Network Communication

The recent advent of advanced network communication technologies allows several functionalities to be used to enhance game experiences. For example, (device) mobility when coupled with network communication enables the instant sharing of locations through physical and ad-hoc activities as real-world interactions. With the facilitation of information exchanges in applications, network communication technologies enable player-interactions in games. In collaborative tasks for example, players are able to gain awareness of the presence of others and to engage in interaction activities through game mechanics. They can also share pieces of information through the communication support.

Figure 24. Hiding in the “shadows”, Left: Outdoor player on the streets, Right: Online view.
(Source: Benford, Magerkurth, and Ljungstrand, 2005)

However, stability issues in network communication (and location) technologies such as inaccuracies, latencies and jitters pose as a key challenge when designing game mechanics. Applying the concept of seamful design, this nature of random fluctuations and uncertainties can be intentionally pegged to various levels of game task difficulty or be used in game systems when players have to seek for its features/constituents (i.e. to locate network hotspots). Hybrid systems that bear interchangeable client-server and P2P architectures allow players to share a consistent game experience that has a highly localized ad-hoc game play such as in "Can You See Me Now" (Figure 24) by Benford et al. (2005). In addition, such adoption of disguising seams as game rules in a game’s design can sometimes be more efficient than outright attempts to solve the problematic technical problems. Due to their unpredictable and random nature, they may be suitable as part of the game experience and rule conditions that lead or grant access to Montola et al.’s (2009) notion of “secretive interfaces” to support hidden manipulations in games (i.e. accessing bonus game levels).

4.3.1.3 Handheld Devices

Handheld devices when used as a platform for AR games bear the inherent characteristics of mobility. They allow players to freely explore the real world and provide as means of physical interaction. Mobility however contains several issues in itself that are affected by contextual factors. Unfocused attention during game play (as one of the issues mentioned earlier in Section 2.2.6) that may occur due to disruptive interruptions is one such issue. Montola et al. (2009) elaborated that time-consuming games set in persistent worlds are pervasive, and that such required effort (i.e., proper setting up/configuration of network and sensing technologies in order to intimately tie the game to the local settings of the different geographical locations (Benford et al., 2005) tends to force players to manage ordinary life and the game. The authors further added that players should be able to resume the last game state for an ongoing game, and be provided "variable pacing" for the game mechanics that they experience. The structuring of the possible game play duration and pacing for a HAR game should thus take into account the context of possible conditions of use (of the game) and mitigate for the anticipated intermittent breaks in game flows to allow for sustainable persistent play.

Form factors (of handheld devices) as personal interaction platforms can exert a certain extent of influence on game experiences. From the analyzed related cases, the presentations of visual effects and interactions for instance may be somewhat restrictive on the small screens of handheld devices. The best pervasive experiences hence should not take place on the small screens (Montola et al., 2009), and the small displays can instead be designed as a metaphoric microscope for observational purposes in the game world (such as Figure 7). With newer technologies in handheld devices, visual presentations can take place everywhere and content can be viewed on the a wider variety of viewing surfaces and from various angles or perspectives. Having a less restricted viewing mode allows interaction possibilities to extend beyond traditional displays. This establishes new forms of intuitive engagement possibilities and reduces the sole reliance on direct device-based manipulations. One example is the use of natural gestures to perform specific actions in games. Form factors of handheld devices that can bring about revolutionary game experiences may also influence the consideration of seamful mitigation measures. The use of projection technologies in HAR games is not included in this study because such feature has yet to be commonly found in consumer handheld devices.

In addition, technical performances may be affected (i.e. slow screen refreshes or frame rates) by the limited hardware capabilities of a platform when the game is overloaded with processing power-consuming tasks that are required by the implemented features (i.e. fiducial marker recognition and real-time 3D renderings are both considered processor-intensive tasks for current handheld devices). The choice of such features should thus be considered from a seamful game design perspective so that the embedded sophisticated technologies are crafted to enhance and not encumber or degrade game experiences.

4.3.2 The Application Level

The second level of game design refers to the applications of the characteristics of applied technologies during the process of game design.

4.3.2.1 Design with Contextual Information

Games on handheld devices can be designed to discern the players' context and then adapt the game experience that follows. In using contextual information randomly in an environment as game events to entice players to look for items in order to achieve objectives, as Montola et al. (2009) termed as "infinite affordances", one possible implementation is handheld location-based AR games. The "Treasure Hunt Game" proposed by (Schmalstieg and Wagner, 2007) utilizes real-world locations in relative association to the game (Figure 25).

(a) (b) (c) (d)

Figure 25. "Expedition Schatzsuche"(a, b): Colour-coding of virtual content indicate states of hotspots (green: free, yellow: in use, red: solved); (c): solving a task by taking a photo of the specific item; (d): locality map indicating all hotspots and their states. (Source: Schmalstieg and Wagner, 2007).

In "Mupeland Yard" (Kuikkaniemi, Turpeinen, Salovaara, Saari, and Vuorenmaa, 2006), gaming takes place wherever the players are. Players play in two social roles to capture the criminal as a detective, or escaping from the game environment as a criminal. Their locations are conceptually integrated using indicative hints on the virtual map. Location as a game element is designed in "POSIT" (Rosenbaum, Klopher, Boughner, and Rosenheck, 2007), for players to explore the buildings with handheld devices that show hints that are situated in the real world. This design idea is based on the use of the indexical environment to allow physical elements to represent themselves in the game (Montola et al., 2009). Another similar work by Eishita and Stanley (2010) utilizes location-specific details as clues for seeking pictures to help reveal the treasure's location. Players physically navigate in the "Team-Based Competitive AR Game" (Mulloni, Wagner, and Schmalstieg, 2008) where the goal is to protect and divert cows by physically moving specific AR markers (Figure 26). Morrison et al. (2009) designed a location-dependent "Treasure Hunting Game". Players must explore the environment to collect clues for completing assigned tasks using GPS. Location information provided by HAR technologies to represent virtual game events in the real world connects the game and actual worlds.

Figure 26. Mobility and social interaction as core gameplay elements. (Source: Mulloni, Wagner, and Schmalstieg, 2008)

4.3.2.2 Design for Learning

Learning with games can possibly retain learners' attention spans and stimulate learning motivations. Kirkley and Kirkley (2004) defined games as learning processes because players are constantly seeking to understand the pattern of the game and repeat it until mastery is attained. As new technologies emerge, it is often necessary to understand the expansive and empowering possibilities that are thus offered in order to better design learning experiences. HAR games for learning (Tran and Huang, 2007; Hong, Jeong, Arriaga, and Abowd, 2010) commonly use HAR technologies to induce the curiosity of the learners to perform associated actions. The “Art History Educational Game” (Wagner et al., 2006) is an educational game for learning art history. Collaborative learning is facilitated through sorting tasks via Wi-Fi. The authors suggested that the AR PDA interface allows players to collaborate more effectively due to the availability of a higher degree of direct manipulation ability over the conventional PC interface. However, one disadvantage of this game that although individual players can have their own game state views, there is no sense of what other players are doing (“shared group awareness”). Interaction in multi-user environments may thus be impaired with this difficulty in designing such collaborative AR systems (Wagner et al., 2006).

4.3.2.3 Design for Social Interaction

Designing for social interaction is one of the applicable areas that can be facilitated by networking HAR technologies. It should be emphasized that although the use of social interaction in game design is not unique to HAR games, the extent of how they employ social interaction is unique (Jegers, 2007). This is because not only simultaneous interaction between the players (either in the competitive or cooperative mode) in real world tasks can be supported, telepresence-enhancing features are introduced as well. The following games employ networked or face-to-face communications to promote collaborative or competitive behaviors and interactions. “The

Invisible Train" (Wagner, Pintaric, Ledermann, and Schmalstieg, 2005) and "The Alchemists" (Broll et al., 2008) are multi-player games that game state and information sharing are constantly being synchronized between the players through wireless networking. "BragFish" (Xu et al., 2008) features a combination of social interaction and co-located HAR elements within the game. To increase awareness of other players' presence, HAR technologies are used to create a shared virtual space in a fishing game that encourages social interaction among the players. Vibrations are triggered when players are reeling the line in and, while a fish is taking the bait. Players are also allowed to "ram" their own boats into others to steal fishes. Such physical player-actions are intentionally designed to be obvious to allow them to quickly gain situation awareness. In "Art of Defense" (Huynh et al., 2009), players cooperatively defend their bases by the collective moving of tangible objects and pressing buttons (on handheld devices) as game play elements. Co-located players can perceive the physical presence of others and engage in direct social interaction during game play.

HAR technologies present several unique game design issues. For instance, players can use physical movements to engage in co-located or remote social interactions which require effective interface metaphors to be conceptualized and implemented into the game design. System performance-related uncertainties such as tracking and communication instabilities should also be designed as integral parts of the game experience. Game design can thus draw on the characteristics and limitations of HAR technologies to construct implementation guidelines.

4.3.3 The Interaction Level

The third level of design involves the interaction layer which focuses on how players interact with the featured game mechanics. AR presentations allow user interactions and interfaces that expand traditional human-computer interaction from 2D to 3D spaces which designers can exploit to create more playful and interesting games.

4.3.3.1 Manipulation

Interaction in 3D environments can be namely differentiated as object manipulation, navigation and system control (Hand, 1997). For HAR games, users can, just like in the real world, interact with virtual objects by directly manipulating physical articles or attributes (they can be mapped to manipulative operations or tasks that are related to the virtual objects). Metaphors that are adopted in interfaces for handheld devices help to ensure that they are intuitive, easy to learn and use, and original behaviors can be performed or enacted without any additional system assistance. This would allow players to concentrate on achieving the game goals instead of having to use inefficient game interfaces.

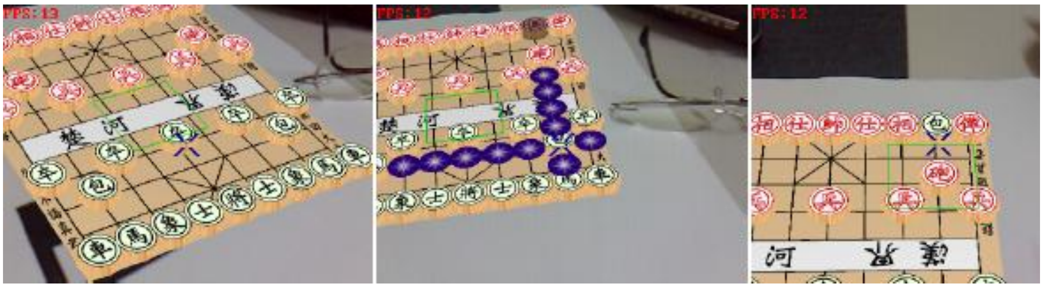
4.3.3.2 Movement-based and Metaphoric Interactions

Handheld devices can be considered as a rich interaction tool with "6-degrees of freedom" (DOF) for representing movements in 3D spaces (translations and rotations) (Henrysson and Billinghurst, 2007). Using inbuilt cameras, computer vision software and a reference coordinate system, sophisticated features such as physical movement tracking (accelerometer, gyroscope, etc.), gesture recognition and screen position-tracking (touch-screen) become possible (Figure 27). This not only mitigates awkward interaction styles (i.e. the pressing of small buttons on a compact keypad), but also leverages game play and provides fun experiences through physically embodied interactions in physical spaces (Xu et al., 2011; Thomas, 2012). One of the goals in the design of AR interfaces is to map appropriate metaphors to interaction design (Billinghurst, Grasset, and Looser, 2005). The following selected games have adopted interaction metaphors:

Figure 27. "6-Degrees of Freedom" interaction for mesh editing task in 3D space on a 2D screen display. (Source: Henrysson and Billinghurst, 2007)

Figure 28. Hand-tilted mobile maze game using inbuilt sensors. (Source: Bucolo, Billinghurst, and Sickinger, 2005)

Bucolo, Billinghurst, and Sickinger (2005) presented the use of a hand-tilted maze to control virtual ball movements in "Mobile Maze" (tiling the phone device in reality as a tangible user interface) to create player enjoyment (Figure 28).



(a) Virtual Chess board **(b) Moving a selected chess piece** **(c) Chess piece is moved to the destination**

Figure 29. A remote handheld "Chinese Chess" game. (Source: Chen, Yu, and Hsu, 2008)

In "Chinese Chess" (Chen, Yu, and Hsu, 2008) players remotely play a game through their connected handheld devices (Figure 29). A virtual chess piece is moved by pressing a physical button, resembling the behavior of playing the actual game.

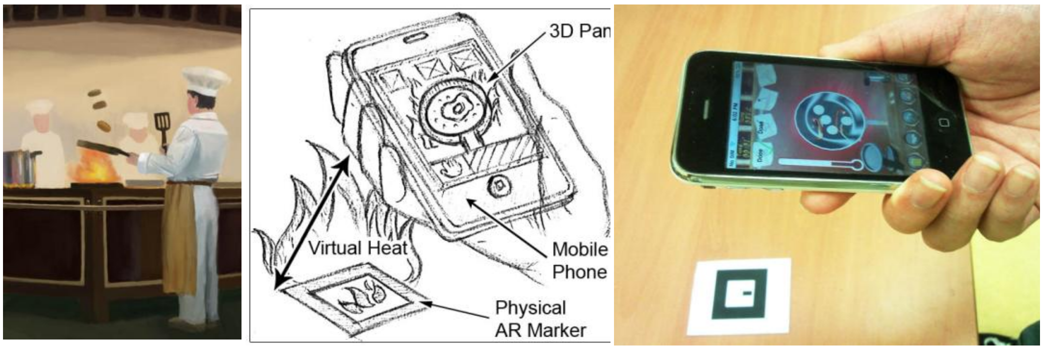


Figure 30. A metaphoric game mechanic ("pan on fire") designed to induce the player to keep the fiducial marker within the device's camera view. (Source: Koh, Duh, and Gu, 2010)

In "Mobile AR Cooking Game" (Koh et al., 2010), players have to perform cooking gestures based on real cooking mechanisms to complete game tasks (Figure 30) intermittently between both 2D and 3D spaces. The work introduces a concept termed as "domain-continuity" to describe such seamful transfers to maintain a sense of flow during content transitions (refer to Section 2.2.6). Game content may bidirectionally propagate in this hybrid game spaces. The concept is useful for building cross-media information spaces between digital handheld devices and non-digital AR triggers (printed media).

The in-game rules and interaction styles of "AR Tennis" (Henrysson et al., 2005) are similar to the real game of tennis. An implicit metaphor to tennis racquets allows players to easily comprehend the game. An additional marker is attached on each phone's back (to detect players' presence) for the effective and appropriate adjustments of behaviors in the collaborative task (Figure 31). When leveraging metaphors with devices, it should be noted that impeding (conflicting) designs with how devices are moved in actual user interactions should be factored (Xu et al., 2011). The lack of movements, through contextual implicitly, can also be an interaction or game mechanic in games.

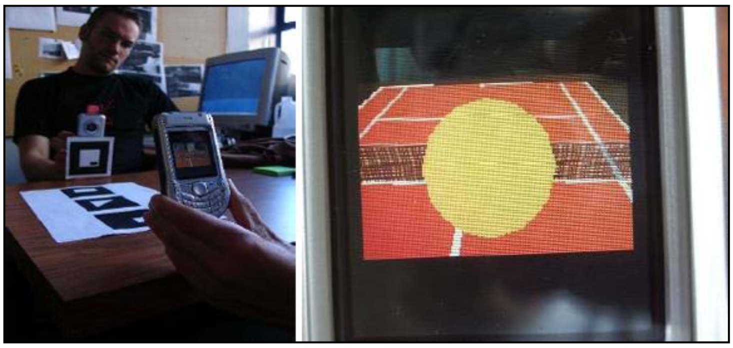
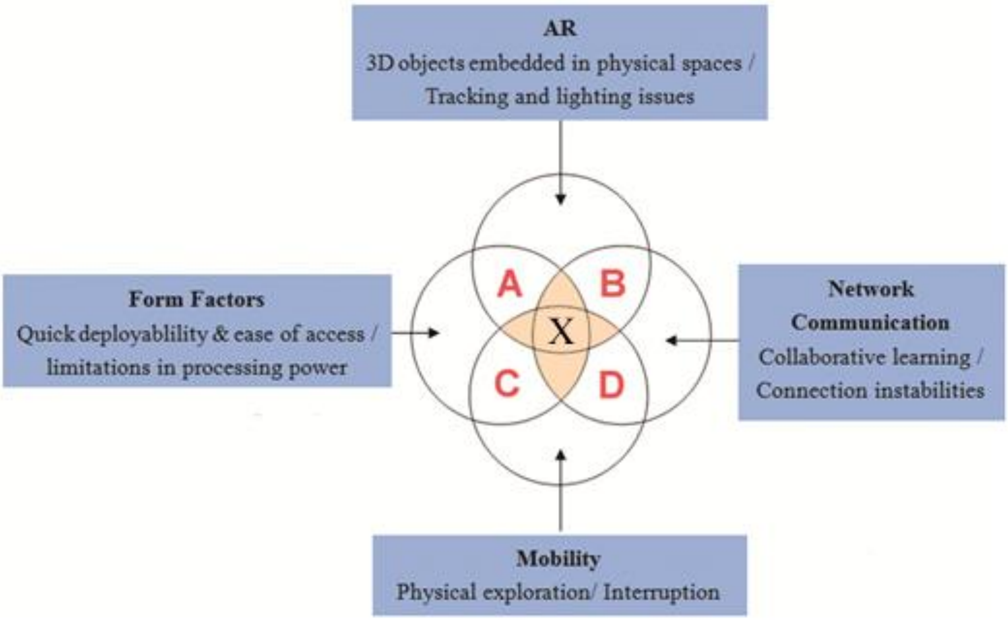


Figure 31. Face to face collaborative mobile augmented reality game. (Source: Henrysson, Billinghurst, and Ollila, 2005)

4.3.3.3 Feedback

Feedback is the unique interaction that is experienced by the players as a game system response following executed action(s) (Salen and Zimmerman, 2004). In the summarized HAR game examples, it can be seen that multi-sensory presentations may be effective measures to provide feedback to players' actions and how game states can be affected with technological performances. Multi-sensory feedback provides players with a sense of being in the game and to understand what is happening in it, as in Henrysson et al.'s (2005) study. In Wagner et al.'s (2006) study, the use of supplementary audio playback and animations to create a multi-sensory experience (using a virtual character) can engage players and be ideal for the screen estate-limited displays of handheld devices. An important game feature in Xu et al.'s (2008) work uses visual feedback to indicate broken game states that are generated from bad tracking performances (Figure 32) so that players can adjust themselves accordingly after seeing such indicators. This is an example of how technological characteristics of HAR that game designers make available for game design can be integrated. These should not intrude into the play experience. The ability to see other people (even without seeing their eyes) and the physicality of moving in open spaces are powerful and appealing visual cueing and feedback mechanisms for collaborative games, as full-body cues can be more naturally supported in AR environments (Thomas, 2012).

Figure 32. Red vertical bars as visual hints in a handheld augmented reality game (right image) indicate that the marker tracking is not currently working. (Source: Xu et al., 2008)



1. System level	Form factors of smart handheld devices, AR libraries, Mobility, Network communication, etc.	
2. Application level	**X** – Overlapped tri/quad-areas of interplay	A contextual **Knowledge-based Domain**, i.e. Learning in the domain of Education.
3. Interaction level	**A** – Overlap between *AR* and *Form Factors*	**Manipulation** – Intuitive use of handheld devices as part of game mechanics
	B – Overlap between *AR* and *Network Communication*	**Feedback -** Multi-sensory feedback / Control of game mechanics
	C - Overlap between *Form Factors* and *Mobility*	**Platform Adoption -** Fits diverse needs of teachers / students
	D - Overlap between *Network Communication* and *Mobility*	**Collaboration** – Mobile social interaction through random encounters with third party(ies)/team member(s)

Figure 33. Interplay of relationships in handheld augmented reality systems.

4.4 Review of Study

This study presents a conceptual design framework for HAR games that is derived from related work, with particular focus on how reviewed HAR games are interlinked in various parts across the three multidisciplinary design levels (System, Application and Interaction). Several other interesting works in HAR games have been omitted since this study only features those where the actual process of game design explicitly manifested. While many of the related works have paid much relative attention to introducing and improving empowering technologies (e.g. tracking efficiencies), HAR game design requires a more formalized design framework for structuring game experiences to be created. From the interplay between the three levels of consideration, the analysis of reviewed HAR games shows how identified design elements in the interaction level relate the affordances of HAR technologies to game and user experiences, as characterized by the in-built game mechanics. Taking the HAR learning games in the study's literature review as an example (Section 4.3), the nature of learning on the whole comprises the inter-dependent variables of AR, network communication, mobility and handheld device technological platforms (Figure 33). Learning effects are complemented by the exploitation of several technologies to visualize (learning) content from a three-dimensional viewpoint, to support the intuitive manipulation of objects, and to provide better control guidance during game play (through multi-sensory feedback), etc. This cohesive "orchestration", as emphasized by Benford et al.'s (2005) study, should also include interventions that are designed to be subtle and not cause disruptions to the game, such as through the use of improvised game messages (i.e. use of visual hints, as in Figure 32).

4.4.1 Framework Definition

The proposed framework in a definitive statement can be read as: ″With an array of technologies (1. System level), the consideration for HAR game design should be motivated by the specific context-dependent and multi-varied context, purpose or goal (2. Application level) and weighed up with the advantages and limitations of identified relevant technologies that are required to realize that application. This is to yield both positive and negative affordances to the degree of becoming influential effects on interaction options and seamful measures for designing game interactions (3. Interaction level).″

4.4.2 Framework's Applicability in Design

Designing HAR games and conceptualizing creative scenarios require several considerations and strategizing that go beyond the traditional conventions of the design process. Game elements that wholly constitute the game mechanics can take into account the three triarchic levels of consideration (Section 4.2.1) in a design process. The concepts and attributes in the three design levels are not mutually exclusive and are non-exhaustive, although in several of the cases that are brought up in this study, a few of them are taken across the different levels for the purpose of discussion. Notably, these identified elements are not meant to be “should-be-followed” rules, but are instead more of a set of governing considerations or design boundaries of featured technologies that can be offered in an HAR game or user experience and should be generated based on availability and applicability of specific needs, features and technologies. The framework can also be useful to identify key issues among interdisciplinary collaborators, which will be discussed in Study 3 (Chapter 6).

4.4.3 Framework Application Strategies

Design strategies for games are mostly holistic in the sense that although they can influence every aspect of game design, they may conflict when applied altogether in a single game (Montola et al., 2009). Relationships that can be established from these three levels of the presented framework thus vary according to the context of the specific application, and the permissible interoperability and applicability. This is especially important for non-game designers to understand and practice. Designers will need to balance between applying conventional game design theories while taking into consideration the characteristics of the technologies and turning them into practical game play advantages and design resources. This will be a focus in the next two studies of this thesis (Chapters 5 and 6).

In a game design, not every known characteristic of featured technologies may be implemented or adopted, and that any corresponding restriction(s) should not be omitted or ignored when a technology is included (Montola et al., 2009). Only a few but essential relationships that are drawn and established from the three respective levels (System, Application and Interaction) are necessary to cohesively form an integrated enjoyable game experience.

Chapter 5. Study 2: A Domain-Centric Game Design Model

5.1 Overview of Study

Based on the conceptual framework from the first study that dictates a three-level interplay between System, Application and Interaction levels for designing HAR games (Chapter 4), this chapter introduces a game design model for translating a grounded domain-based theory into practical game design considerations and game structures. The domain of education is adopted for this purpose. In order to address validity and applicability on the model, a game prototype for situated history learning has been developed using one of the four possible implementation types with the model ("The Jackson Plan"). A user study was conducted to assess the effectiveness on learning performance using the designed HAR game media. The empirical evaluation assessed knowledge material transfers (as communication goals of the game media) by evaluating the participants' ability to apply communicated domain knowledge within the preset assessment context (history learning). The proposed game model provides designers with a pivotal and organized structure to assess and establish design requirements for interdisciplinary game projects.

5.2 Procedures

5.2.1 A Game Design Model

A model for designing educational HAR (eHAR) games is proposed where the dichotomous extents between the availability of collaboration and location-based services (LBS) features represent the distinct HAR technology pairings that can be made (0=No, 1=Yes), resulting in four possible eHAR game types and play styles that are achievable (Figure 34). Collaboration and LBS are drawn as the technological criteria because they are key aspects of AR that are closely co-related with learning. Thereby four design processes can be initiated from here, where the triarchic Application-System-Interaction levels of structural relationships (Section 4.2.1) can be established for each respective game type. This game type differentiation informs the range of employable technologies in mobile devices and supporting platforms, and subsequently affects available interaction options for the game to be developed.

Initiating a new eHAR game project, a selected educational learning theory is first applied at the model's top level, and a game type is determined (LBS and collaborative features). To operationalize the selected learning theory, a supporting instructional strategy is then identified through literature to match (non-exclusively) the appropriate mechanisms and approaches to compatible learning objectives. Next, an educator matches the required learning objective(s) of an educational curriculum to Krathwohl et al.'s (2001) "taxonomy of cognitive process". The cognitive process is the core dimension in the classification of learning objectives in the model because in pervasive AR game settings, knowledge is socially situated and embedded in authentic activities. The described process yields comprehensive implementation approaches in the Application level that support the selected learning theory's ideology. System level and Interaction level considerations that follow next have to support the "required" approaches in the Application level. The results of these cross-domain inferences in the triarchic framework (Chapter 4) are useful to determine platform specifications, as well as being core attributes for designing game mechanics.

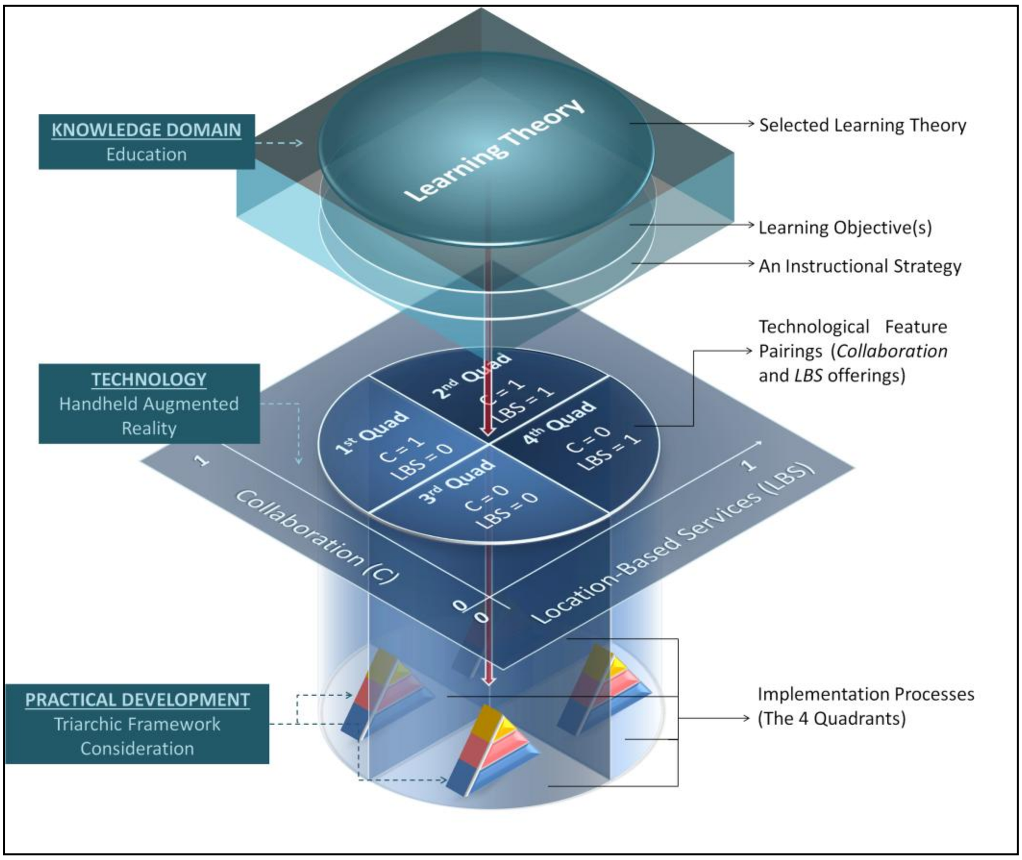


Figure 34. Proposed game model for domain-centric handheld game design (illustrated using "education" as the knowledge domain).

5.2.2 “The Jackson Plan” Game Design (Part 1)

5.2.2.1 Context

“The Jackson Plan”, also known as the “Plan of the Town of Singapore” is an actual urban town plan drawn up in 1822 by Lieutenant Philip Jackson, an engineer and land surveyor of the British colony, to manage the early multi-racial (predominantly the Chinese, Malays, Indians and British) immigrant settlements (Figure 35, Middle and Right), and is named after the same. It is an important chapter for lower secondary history students in Singapore public schools (CPDD, 2007), about Sir Stamford Thomas Bingley Raffles’ (Figure 35, Left) founding of modern Singapore in 1819 as an important trading seaport. The chapter links several important geographical sites for key historical events and trade activities that were conducted by the then-populations that followed with the founding, and is selected because the historical landmarks along Singapore River (Figure 36) provide a rich context to explore designs for situated discoveries in relation to the game model that is being developed through this research. The learning experience of this history chapter was to be made as a short and light location-based game (LBG) experience with HAR features for selected “contextually-relevant” (Giiven and Feiner, 2006) places, as shared in the next section.

Figure 35. Artifacts photographed at National Museum of Singapore, (Left): Portrait of Sir Stamford Thomas Bingley Raffles. (Middle, Right): “Jackson Plan” (1822) / Close-up.

Figure 36. The Singapore River today: Play-site for "The Jackson Plan".

5.2.2.2 Theoretical Design and Development (Study)

The steps taken in the design and development of "The Jackson Plan" LBG study are described in this section to elaborate on how the proposed theoretical model (Section 5.2.1) and triarchic framework (Section 4.2.1) may be applied in practice.

1. System level

Step 1. Defining technologies and possible platform(s): To support a game that is of an exploratory and contextually rich nature, it was important to know players' positions and orientations relative to the "game world" (as discussed in Section 2.2.5). GPS tracking on a handheld device was opted for this purpose. A digital tablet was chosen over a smart phone because a larger screen display would ease reading in an outdoor environment. The various hardware features of the handheld device (Apple iPad2[10]) that could be used in interaction designs were still/video photography, accelerometer, gyroscope, touch-screen while software aids included natural feature AR tracking and game engine support. 3.5G connectivity was the only mobile data option that was readily available.

[10] http://www.apple.com/ipad (Last retrieved: 1 November 2012)

2. Application level

Step 2. Embedding learning theory: The LBG was intended to aid the learning of “The Jackson Plan” chapter that involved visiting several important historical sites of the multi-racial immigrants’ trade activities that occurred after Sir Stamford Thomas Raffles’ founding in the year 1819 of modern Singapore as a seaport (CPDD, 2007). “Situated cognition” (Brown et al., 1989) was embedded as the learning theory in the view that meaningful learning is possible through authentic activities and social interactions.

Step 3. Determining game type: With vital historical contexts lying across several geospatial sites at the Singapore River (Figure 36), LBS and collaborative features complemented situated gameplay (Squire et al., 2007).

Step 4. Identifying learning objectives and instructional strategy: The learning objectives of the academic curriculum are to aid students to develop their skills to “Understand, Apply, Analyze and Evaluate” through historical events (checked as **red arrows** in Table 2). “Scaffolding” (Hill and Hannafin, 2001) was used as the instructional strategy to establish the relevant Application-level approaches in Table 2.

Table 2. Applied design model in the domain of education with selective references to respective concepts in discussion.

<table>
<tr><td colspan="3">Knowledge Domain: "Education"
Learning Theory: "Situated Cognition" (Brown et al., 1989)</td></tr>
<tr><td>Game Type
(A technological consideration)</td><td colspan="2">LBS: Yes / Collaboration: Yes</td></tr>
<tr><td colspan="3">System level</td></tr>
<tr><td>Attributes</td><td colspan="2">Consideration(s) and Measure(s)</td></tr>
<tr><td>AR System</td><td colspan="2">Browser-based (Outdoors), Camera availability</td></tr>
<tr><td>Form factor</td><td colspan="2">Smartphone device - Designing for limited screen estate on touch-based screen.</td></tr>
<tr><td>Networking</td><td colspan="2">3G/WiFi for real-time activity feedback.</td></tr>
<tr><td>Mobility</td><td colspan="2">Instill contexts from specific locations (GPS/Wi-Fi). Gameplay durations should take into account signal stabilities (3G/GPS) and devise non-connectivity measures.</td></tr>
<tr><td colspan="3">Application level</td></tr>
<tr><td rowspan="2">Learning Objectives
(Educators select from this column, checked in ✔)</td><td colspan="2">Instructional Strategy (Supporting the selected Learning Theory)</td></tr>
<tr><td>Mechanism(s)</td><td>Approach(es)</td></tr>
<tr><td>Taxonomy of "Cognitive Process" (Bloom,1956)</td><td colspan="2">"Scaffolding" (Hill and Hannafin, 2001)</td></tr>
<tr><td>Remember ✔</td><td rowspan="2">- Conceptual</td><td rowspan="2">Information-visualization (Toth, 2000).</td></tr>
<tr><td>Understand ✔</td></tr>
<tr><td>Apply</td><td>- Conceptual
- Procedural</td><td>Explicit guidance (Azevedo, Verona, and Cromley, 2001).</td></tr>
<tr><td>Analyze ✔</td><td>- Conceptual
- Procedural
- Strategic</td><td>Feedback (Azevedo et al., 2001), Expert guidance (Saye and Brush, 2002) and Peer Interactions (Li and Lim, 2008)</td></tr>
<tr><td>Evaluate ✔</td><td rowspan="2">- Conceptual
- Procedural
- Strategic
- Metacognitive</td><td rowspan="2">Problem-based Inquiry (Saye and Brush, 2002), Questioning and Prompts (Li and Lim, 2008)</td></tr>
<tr><td>Create</td></tr>
<tr><td colspan="3">Interaction level</td></tr>
<tr><td>Attributes</td><td colspan="2">Consideration(s) and Measure(s)</td></tr>
<tr><td>Manipulation</td><td colspan="2">Touch interface, orientation-sensing (using accelerometer and gestures), and location/contextually-induced event triggers.</td></tr>
<tr><td>Feedback</td><td colspan="2">Visualizations of ambient and embedded sensor data (Koh et al., 2010), Haptic (vibrations), Digital audio, Co-located or remote social interactions.</td></tr>
<tr><td>Platform</td><td colspan="2">Secondary user-input (photo taking) can be an activity in the game. Specific information can be tied to Time and Space (Squire et al., 2007).</td></tr>
<tr><td>Collaboration</td><td colspan="2">Non-linear progressive task completion (sites and virtual items may not be visited/used in order). Game play is cooperative.</td></tr>
</table>

3. Interaction-level

Step 5. Extrapolating feasible game system features from intended learning objectives: Traits of software and hardware technologies to support Application level "approaches" were identified. To support feedback for the photo-taking activity, mobile data connectivity was included (System level's "Networking" attribute in Table 2). Possible design limitations that were related to technological "shortfalls" (anticipated tracking inaccuracies, mobile signal instabilities/irregularities, and limited screen displays, network latencies and jitters) were identified. These undesirable effects were to be negated or reduced through the intentional inclusions of design measures in the game system that directly addressed the technical constituents (Montola et al., 2009: Koh et al., 2010) (in Interaction level), i.e. a hidden moderator's function was included in the game's segmented in-game map (you earn new "pieces" with game progress, as in Figure 37) that allowed manual corrections of players' locations in the event of GPS location-tracking inaccuracies.

Figure 37. Segmented progressive in-game map (3 pieces).

Step 6. Determining interaction designs, activities and game mechanics: Possible player and HAR interactions with System-level features to accomplish the intended game goals (in Application level approaches) were identified from literature; an adventure game structure (Montola et al., 2009;

Ju and Wagner, 1997), linearity in narrative design (Dow et al., 2005) and HAR effects (geo-registered panorama art, photo-taking activity, physical feature recognition through vision-based AR and collaborative mini-games) to bridge historical contexts to evocative places (Wither et al., 2010). The rationales for adopting these features is described in fuller detail in **Study 3** in Section 6.2.2.2. This step established the design requirements for the feedback mechanisms of game interactions.

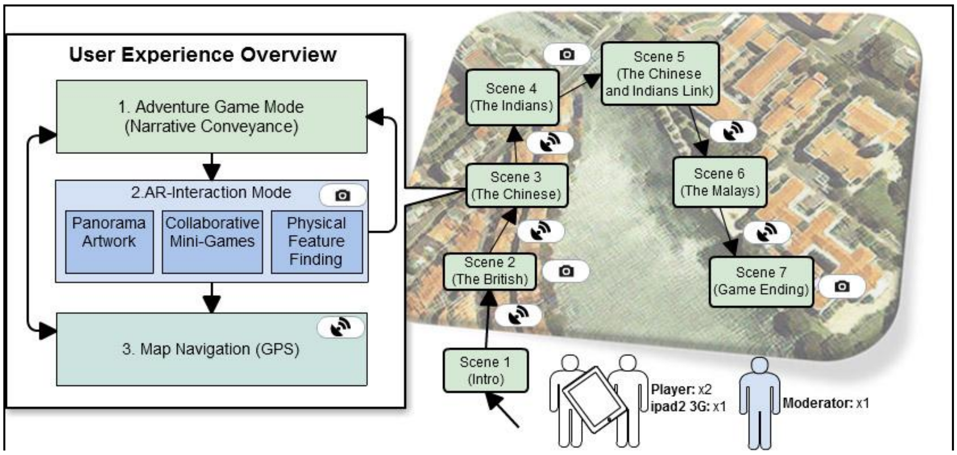


Figure 38. Activity design for the educational location-based game trail.

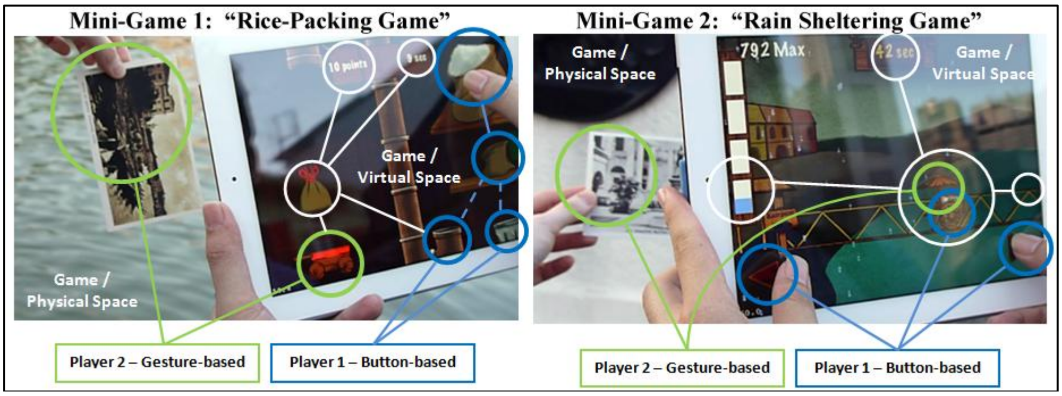


Figure 39. Designed interactions for mini-games (Circled): Green: Player 1, Blue: Player 2, White: Common game goals.

Table 2 was subsequently used in the creative and technical development of the game prototype by designers and developers with iterative feedback from an education researcher (discussed in Chapter 6). Measures that addressed System level and Application level approaches (see Table 2) were translated into the game's design themes, narrative and designed activities (Table 3). Designed activities were respectively scattered along the intended physical trigger spots along the pre-assessed game trail (Figure 38) while collaborative mini-games ensured that players were dependent on each other's actions and communication efforts to win (Figure 39) using "touch" and "orientation" sensing (under "Manipulation" attribute in Table 2).

Step 7. System development: "Cocos2d"[11](2D game engine for iOS development on Apple iPhone/iPad), "LUA"[12] (for scripting game events) and "Qualcomm Vuforia" ("Developing with Vurofia", n.d.) (AR library) were used to develop the prototype.

Step 8. Game balancing: Interactions were iteratively playtested during development in the research lab to improve interaction intuitiveness, fun and enjoyment (balancing activities and designed challenges). This was subsequently extended to on-site playtesting at the Singapore River to determine persistent external environmental issues that might affect the gaming experience (i.e. GPS inaccuracies).

Step 9. Review: The completed prototype was briefly reviewed by a history teacher before the evaluation (next section).

[11] http://www.cocos2d-iphone.org (Last retrieved: 1 November 2012)
[12] http://www.lua.org (Last retrieved: 1 November 2012)

Table 3. Translating learning concepts into knowledge-based design styles.

Column 1	Column 2	Column 3	Column 4
Learning Concept	**Design Themes**	**Narrative Development**	**Activity Design**
1. Background of Singapore Settlement	* Small fishing villages * Trading activities at dockyards * Mixed populations (multi-racialism) * British-shops	Players are assigned to locate the missing "Jackson Plan." They are also asked to talk to several people (NPCs[13]) to gather background information.	Players are to pick up virtual items in a geo-referenced panorama artwork of the past.
2. Entrepot Trade	* Daily lives of coolies/workers (multi-racialism) * Middlemen's trade roles * Food depots (i.e. rice and tea) * Chinese factories	Players learn the primary trade activities of the population group (importing and exporting of goods) by talking to the Chinese middleman (NPC) in the rice factory.	Players experience the 2-player "Rice-Packing" mini-game that requires teamwork using the same device.
3. Contributions of Immigrants	* Emphasis on cotton trade * "Elgin Bridge," A monumental bridge that once served as a trading link * Dockyards	Interacts with a virtual Indian coolie (NPC) who explains his job and livelihood to Players. He provides navigational information to the next point of the game.	Players are required to take the photograph of the correct prominent physical feature situated along the predesignated route. They play the "Rain-Sheltering" mini-game of synchronized movements.
4. Comparisons of Immigrants' contributions	* A Malay village along the river * Supplies and service provisions (i.e. Malays shipbuilders) * Raffles Landing Site / "The Statue of Raffles"	A Malay elder (NPC) acts as a facilitator who helps Players to organize and reflect on the overall information fragments from the gaming experiences (who have they met and their respective contributions to the settlement).	Players unlock a secret virtual document through markerless-AR (natural feature) recognition of a physical feature at this location (The "Statue of Raffles" at the Raffles Landing Site).

[13] Non-playable characters (NPCs): A NPC is any character that is not controlled by a player in a game. NPCs are instead controlled by scripted events or artificial intelligence.

a) Location-based AR trial b) Digital book trial

Figure 40. Students in evaluation trials.

5.2.3 Prototype Evaluation (Quantitative)

A user study on "The Jackson Plan" LBG was conducted to understand the impact and limitations of a game implementation that was created using the proposed eHAR design model. A quantitative evaluation was conducted to assess the game prototype in supporting learning based on the factors of learning performance, motivation, learning strategies and engagement. The location-based AR version of the game was compared with a non-AR digital book (Figure 40) that contained identical learning content on the same platform (Apple iPad2). The digital book activity was used because it is a main method of reading activity on handheld devices.

Learning Performance: Learning implicates acquiring and modifying knowledge, skills, beliefs, attitudes and behaviors. Outcomes result from organization and processing information (Schunk, 1991).

Motivation: It is a major variable that influences all phases of learning and performance, and cognition theorists assert that it can also help students organize and process information (Schunk, 1991). “Game-based learning” is in particular an entertaining approach to learning. Motivation allows educators to map curricular content into gameplay and these game-like qualities of subject matter may have greater possibility for students to develop intrinsic motivation for learning (Squire et al., 2008). Most educators believe that motivation can affect learning in many ways, and teachers have to consider factors such as instructional practices and classroom factors to ensure that students remain motivated to learn (Schunk, 1991).

Learning Strategies: Designs that are based primarily on users’ needs and tasks may overlook potential innovations of new technologies (Gaver, 2001). A regimen of deliberate organized instructional materials instead enhances learning performance while reducing cognitive limitations (Schunk, 1991).

Engagement: It activates student collaborations and encourages students to take an active role when confronting new problems. Interactions with other learners and materials enable students to analyze, synthesize, evaluate, and employ critical thinking skills as they determine their course of actions. Designing engaging learning is not only desirable, but also a necessary element for education settings in today’s technology-oriented world (Dickey, 2005). The multimodal and interactive nature of AR technology fosters learners’ engagement, immersion and learning support (Billinghurst and Dünser, 2012).

5.2.3.1 Participants and School Selection

The pilot study involved 72 student volunteers (37 females, 35 males) of between 12 and 13 years old who were randomly selected from 3 Secondary One history classes in a public school in Singapore. The request to the school was for as many participants as possible. A larger sample size was preferred due to the quantitative nature of the study. None of the students had completely studied nor was briefed on the history chapter ("Different immigrant communities play in Singapore's development" (CPDD, 2007) prior to the study. The selected history chapter is taught in all public schools in Singapore that follow the Ministry of Education's syllabus (History Syllabus, 2005). Due to logistics and time constraints, the school was picked because of its close proximity to the Singapore River test site. The participants were familiar with using PCs and mobile phones, and had some prior play experiences with non-location-based handheld games.

5.2.3.2 Experiment Setup

A between-subject design (digital book and location-based AR versions) was applied. The participants were selected and mixed by a teacher to ensure social and cognitive homogeneity as 36 dyads [14] which were randomly assigned to one of the two experimental conditions. 18 dyads each played a respective version of the game prototype that contained identical learning stages. Each group was provided with an Apple iPad2 device and a postcard AR marker (for the location-based AR condition). A moderator introduced the game and accompanied each outdoor dyad for safety reasons.

[14] A dyad, in sociology, is the smallest possible social group of 2 people who share similar objectives and interdependent relationships. It is characterized by reciprocal interaction and relatively equal involvement between members (Ritzer, 2007).

The groups filled a demographics form (Appendix A), received a 5-minute briefing on the game tasks (Appendix B) and a multiple-choice test immediately followed to gauge their prior knowledge on the history subject (Appendix C). Sessions were held in two physical spaces, one at the present **Boat Quay** along the Singapore River where the first settlement was established (for the location-based AR game group). Participants in the digital book-based group had their sessions in a computer laboratory in their school, which were also led by a moderator. Players were free to assume which of the two in-game characters to play as but were told that they could swap places if desired during the game. Upon completion of the gameplay activity, the participants answered another questionnaire (Appendix D) and a multiple-choice test (Appendix E). This evaluated the knowledge that students had acquired through the game content, activities and play experiences.

5.2.3.3 Digital Book-based Group (Control Group)

Students in this group experienced the same assessment phases and game tasks with the location-based AR group. Table 4 shows the differences between the two conditions.

Table 4. Differences in evaluated experimental conditions.

	Digital Book	**Location-based AR**
Platform	Apple iPad2	Apple iPad2
Collaboration	Yes	Yes
Interaction Type	Non-AR	Location-based AR
Play Space	Indoors	Outdoors

5.2.3.4 Instruments

Few studies have formally investigated the value of AR for learning in educational settings (Billinghurst and Dünser, 2012). In this study, pre- and post-test questionnaires and a learning achievement test were used to measure the educational impact of the game prototype. The pre-test questionnaire (Appendix C) gauged learners' prior knowledge on the curriculum while the post-test questionnaire (Appendix D) measured the learners' understanding of facts, knowledge application from the gameplay through their levels of motivation, learning strategies and engagement. Learning achievement tests were conducted before and after the gameplay using multiple-choice tests that were designed by an education researcher in collaboration with a history schoolteacher (Appendix E). Questions in the questionnaire were adapted from Pintrich, Smith, García, and McKeachie's (1991) manual on using motivated strategies for learning and from Brockmyer et al.'s (2009) study for measuring game engagement. The post-test questionnaire contained a total 27 items that required short statements to assess learners' motivational orientations, use of various learning strategies, and their engagement levels during game play. Responses were modulated on a five-point scale, ranging from 1 (not true of me at all) to 5 (very true of me).

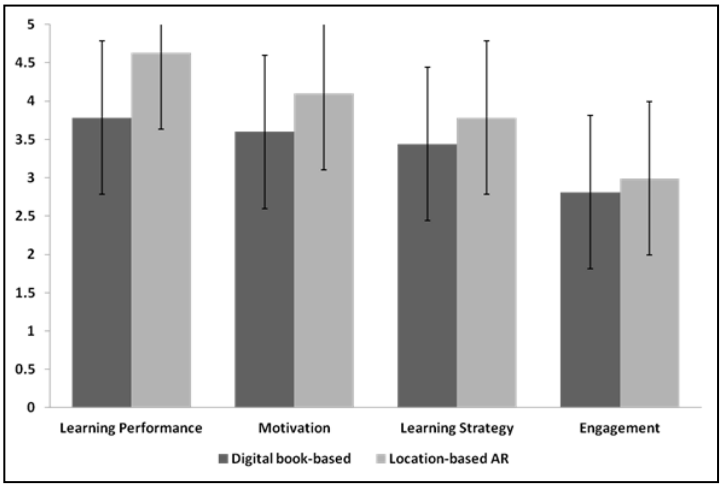


Figure 41. Evaluation on learning.

5.2.3.5 Results

Results are reported in corresponding sections on learning performance, motivation, learning strategies and engagement (Figure 41). Reliability analysis was conducted for every reported questionnaire index, which yielded satisfactory values (α=>.70). The indexes were modulated on 5-point scales (1= negative; 5= positive).

Learning Performance

The game prototype has an overall positive educational impact on learners. A paired t-test of the learning performances from the two conditions showed that participants obtained significantly higher scores in the post-test ($M = 4.20$) than the corresponding pre-test ($M = 3.65$), $t(71) = -4.31$, $p < .001$, $d=1.02$. An independent t-test was further conducted to analyze whether there was any difference between the two conditions in the pre- and post-tests. The results of a one-tailed test indicated that the location-based AR group ($M = 3.80$) did not significantly differ from the digital book-based group ($M = 3.50$) in the pre-test. However, a significant difference in learning performance was found in the post-test for the two conditions, $t(70) = -3.28$, $p = .001$, $d= .78$. Students in the location-based AR group ($M = 4.63$) performed significantly better in the post-test than students in the digital book-based condition ($M = 3.78$).

Motivation

Responses on the dimensions of intrinsic goal orientation, task value and self-efficacy were aggregated. Students were overall more motivated in the location-based AR condition ($M = 4.10$) than those in the digital book-based condition (M = 3.60), t(70) = -3.02, p = .002, d= .72. A between-subjects independent t-test of the overall measures revealed that motivation factors were significantly higher in the location-based AR condition: Intrinsic Goal orientation – "learners" perceptions on why they are engaged in a learning task" (t(70) = -2.68, p = .005, d=.63); Task Value – "student's evaluation of how important, interesting and useful a task is" (t(70) = -3.12, p = .002, d=.74) and Self-efficacy – "a self-appraisal of one's ability and confidence to perform a task" (t(70) = -2.36, p = .01, d=.56).

Learning Strategies

Students in both conditions demonstrated through their behaviors and responses in the questionnaire that the game helped them to apply cognitive strategies by integrating prior knowledge to the new information to be learned during game play. Participants in the location-based AR condition scored significantly better (M = 3.78) in the questionnaire than those in the digital book-based group (M = 3.44) in learning strategies (t(70) = -2.22, p = .015, d=.53). The dimensions of learning strategies (Schunk, 1991) were further analyzed as follow:

Elaboration: "Students store information in their long-term memory by building internal connections with items",

Metacognitive Self-Regulation: "The control and self-regulation of cognition through learners' improvements in performance by fine-tuning and continuously adjusting their cognition activities" and, *Peer Learning*: "Collaboration with peers help learners clarify course materials to reach insights that they may otherwise not have attained."

A between-subjects independent t-test of the dimensions of learning strategies indicated significantly higher ratings for Elaboration and Metacognitive Self-Regulation in the location-based AR condition ($t(70) = -3.39$, $p = .001$, $d=.80$; $t(70) = -1.78$, $p = .04$, $d=.42$ respectively). No significant difference emerged in *Peer Learning* between the digital book-based condition ($M = 3.52$) and the location-based AR condition ($M = 3.54$). This is likely because of the same collaboration opportunities in the two conditions.

Engagement

Participants' scores for engagement were positive in both conditions as there was no significant difference between the digital book-based condition ($M = 2.81$) and the location-based AR condition ($M = 2.99$). This is probably because several of the participants in the location-based AR condition experienced game interferences that were caused by inaccurate GPS readings that resulted in them facing the wrong directions during physical navigations. There were also distractions from nearby shops, traffic and pedestrians along the game trail. These events interrupted the gaming experience and caused frustrations to users. It was noted that a few participants in the location-based AR condition initially had difficulties to coordinate their AR interactions for the mini-games or showed unanticipated interaction behaviors (these were users who were found to be lacking experiences with handheld devices from the Demographics

Questionnaire, see Appendix A). They would sometimes temporarily swapped their game character roles or physical positions during the mini-games to attempt alternate strategies for winning game challenges (Figure 42). Student participants in the digital book-based (control group) condition did not exhibit this behavior.

Figure 42. Assuming wrong physical positions during mini-games (Facing the screen, Player 1 with the physical card, is intended be on the left side next of Player 2).

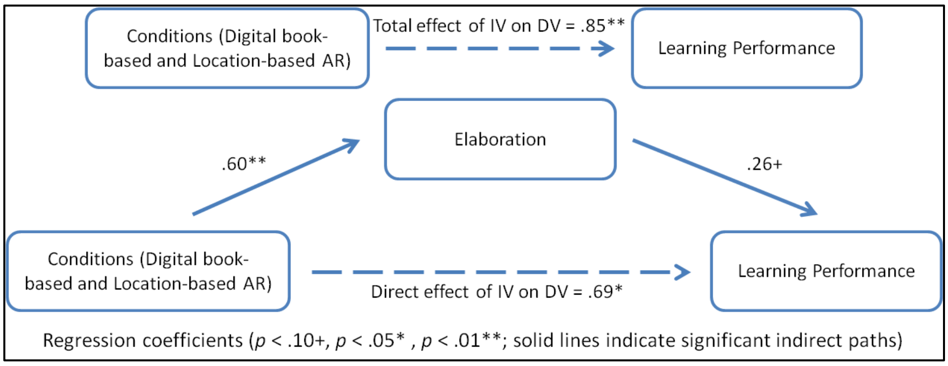


Figure 43. Model: mediatory effects on learning performance.

Mediation Effect of Elaboration on Learning

An indirect effects test (Hayes, Preacher, and Myers, 2010) was conducted to understand the underlying mechanism for the participants' improvements in learning performance (Figure 43). Mediation variables played a significant role between the independent variables (IV) and dependent measures. IVs directly and indirectly influenced the dependent variables (DV). Mediators caused indirect effects of IV on DV. Confidence intervals of indirect effects that contained zeroes were interpreted as insignificant. This implied that there were no causal relationships between the IV, the mediator and the DV. The results indicate that elaboration as a learning strategy mediated learning performance. Bootstrapping results show that indirect effects through elaboration were significant, b = .16, 95% C.I. from .01 to .43, SE = .11, while motivation (b = .03, 95% C.I. from -.11 to .23, SE = .08) and engagement were not (b =.003, 95% C.I. from -.05 to .10, SE = .03). Elaboration is hence an efficient mediator that has led to higher learning performance in the location-based AR condition over the digital book.

5.3 Review of Study

5.3.1 User Study

In this study, the proposed game model has inspired the design of a robust learning activity in educational settings. Mediation analysis revealed that "elaboration" (learning strategy) is the strongest factor in the acquisition of knowledge in this study, i.e. through instructional scaffolds and tailored learning objectives via designed collaborations and gaming tasks that helped learners to build inner connections with concepts to be learned (knowledge integration). Learning contexts were apt to the intended expected outcome(s) to be learned. The students demonstrated positive collaboration skills with their partners in the evaluated conditions. The impact of “The Jackson Plan” LBG has been examined through a user study with results suggesting that the method is able to produce an eHAR game or gaming experience that aids learning (determined by a user who can successfully apply communicated knowledge through a designed medium). The proposed design model and described methodology in this study can be useful for interdisciplinary collaborators to convey explicit requirements and needs in a project.

5.3.2 Design Issues for Designers

On Interaction Design - Engaging multimodal interface designs promote and increase user participation, collaboration and engagement (Jimenez Pazmino and Lyons, 2011). Gaming activities reinforced the learners’ understanding of the “entrepot trade” history chapter in “The Jackson Plan”. Although the digital book contained the same learning content on the same platform, it is argued that learners had assumed a more active role when progressing through the various real-world sites and contexts of the learning phases and experiencing interactions (locative or HAR features) that were triggered by geo-locations during the experiment. Interactions with content might have invoked learners’ prior knowledge from memory and transfer such information to new problems better than passive lectures (Billinghurst and Dünser, 2012), but these need to be thoroughly playtested to minimize undesired user interaction behaviors (Figure 42), disorientations or odds of players getting stuck or lost in physical places (MacIntyre et al., 2001). Game states or statuses of players in the game world should factor these real-world issues in a game's design.

On Engagement - Distractions in outdoor environments continue to pose design challenges for eHAR games and HAR games in general. Presenting narrative content in discrete chunks in a mobile setting makes it difficult to retain participants in the story's flow. This is because the connection with narrative material is often lessened as users tend to focus on the real surroundings instead (Wither et al., 2010). The evaluation assessment did not suggest that learners are better engaged with location-based and HAR features than a traditional digital book but the use of such features may instead be motivated by the inclination to include physical objects or sites as part of the user experience design (i.e. to see Raffles' statue as a designed activity for a visiting tourist).

5.3.3 Guidelines for Designers

The following guidelines have been established from the development experiences from this study:

1. Instructional materials or knowledge-based components should be integrated and organized in minute steps in design to balance between knowledge and technology (i.e. use of narratives that tightly complement designed physical or geo-specific activities).

2. Designers who are new or unfamiliar with conceptualizing scenarios for HAR gaming experiences as a product or service should start by exploring design possibilities with different interaction modalities that exist within systems. The technological factor is important and can often introduce novelty into designs of fun experiences.

3. High and active user engagement should not be assumed. Interruptions from daily activities of our lives should also be factored into any activity design for HAR gaming experiences. Depending on the use case, designs may also consider whether it would be “socially-acceptable” for a user to retrieve his or her handheld device to start an augmented experience that might entail seemingly “awkward” body postures or gestures. This is an important factor to note for designing HAR games for use in public spaces, i.e., Grubert et al's. (2012) work. User interfaces in the HAR application could include “pause” and “recovery” measures for players to suspend or resume interactions between breaks.

5.3.4 Limitations and Directions for Future Work

A systematic overarching of learning content by classifying learning objectives and stratifying learning strategies support eHAR game designs. A challenge however lies in the designs of eHAR applications because non-technical collaborators (i.e. designers and educators) tend to understand little about technology and similarly with that of technical developers on design and education (Billinghurst and Dünser, 2012). This will be the topic of discussion for the next study (Chapter 6). Interpreting the selected learning theory into game design considerations establishes a bridge between curriculum materials. The early but extensive work in the model that is presented in this chapter has several limitations:

1. In order to provide initial validity to the proposed design model, only a single learning theory has been adopted for the study.

2. The evaluation assumed that the diversities and differences of the learners' cognitive styles and their prior use experiences in handheld devices would be randomly distributed in the conditions.

3. Game genre selection is not a scope of this study because "a single game does not make a genre" (Montola et al., 2009). Due to time constraints for this study, the evaluation of the proposed prototype did not include qualitative data such as students' opinions on LBS or HAR features.

Future work for this study is to address the above issues and further evaluate the game model by producing other games using the proposed model (i.e. for the other three game types in Figure 34). The extension of the proposed model to other knowledge domains will be an interesting direction for future work as well.

Chapter 6. Study 3: Co-Creativity Fusions in Interdisciplinary Handheld Augmented Reality Game Developments

6.1 Overview of Study

This study examines and focuses on real-world implementation issues when the theoretical model (Section 5.2.1) is applied in practice by reflecting on the practice-led generative design (Bidwell and Holdsworth, 2006) transpirations of an internship work arrangement (described in next section) with two design students, both as “full” practitioners in 2D art and game design developments respectively for “The Jackson Plan” game prototype implementation in **Study 2**. The tertiary students worked in an interdisciplinary collaborative environment with three researchers from technical (technology), design (author of this thesis) and social science (education) backgrounds. The aim was to co-develop the outdoor location-based game prototype for Study 2 (Chapter 5) during the students’ 6-week internship. Empirical observations based on the project's translated knowledge-based design components, co-creativity roles, design outcomes of the collaborators involved and qualitative interviews with the student-artists revealed media design practice and collaboration issues from this interdisciplinary experience in a real AR game development process using the game model (Study 2's).

The case study is primed as a successful development with student-artists that may be useful to inspire subsequent work with such an interdisciplinary design approach using the proposed methodological tools (framework and model). The practice-led study relates how a clearer understanding of such didactic situations can realistically empower and invoke co-evolutions of both art and technology in AR as a new media while working with domain knowledge.

6.2 Procedures

6.2.1 The Initiative

The Keio-NUS CUTE Center in the National University of Singapore[15] has hosted student interns from the Design School's "Diploma in Games Design and Development" program in Singapore Polytechnic (SP)[16]under their 6-week "Industrial Training Programme" (ITP) since 2009. This is also commonly known as an "internship" where students are attached to an external organization to gain practical work experience related to their field of study. In past batches, each student of game design and/or digital art (2D or 3D) specialization(s) (varied according to the specific design skill set request to the school) was assigned to at least one graduate researcher of humanities (social science or design) background, and one other graduate staff researcher of either computer science or engineering background, and worked in interdisciplinary Games, Education, Mobile and AR related projects.

[15] http://cutecenter.nus.edu.sg/
[16] http://www.sp.edu.sg/

Table 5. Translations of learning concepts to design elements (Individual and Group).

Individual Developments (*rE* only)		Co-Creations (Group)	
Column 1	Column 2	Column 3	Column 4
Learning Concept	Design Themes	Narrative Development	Activity Design
1. Background of Singapore Settlement	* Small fishing villages * Trading activities at dockyards * Mixed populations (multi-racialism) * British-shops	Players are assigned to locate the missing "Jackson Plan". They are also asked to talk to several people (NPCs) to gather background information.	Players are to pick up virtual items in a geo-referenced panorama artwork of the past.
2. Entrepot Trade	* Daily lives of coolies/workers (multi-racialism) * Middlemen's trade role * Food depot (i.e. rice and tea) * Chinese factories	Players learn the primary trade activities of the population group (importing and exporting of goods) by talking to the Chinese middleman (NPC) in the rice factory.	Players experience the 2-player "Rice-Packing" mini-game that requires teamwork using the same device.
3. Contributions of Immigrants	* Emphasis on cotton trade * "Elgin Bridge"- A monumental bridge that once served as a trading link * Dockyards	Interacts with a virtual Indian coolie (NPC) who explains his job and livelihood to Players. He provides navigational information to the next point of the game.	Players are required to take the photograph of the correct prominent physical feature situated along the predesignated route. They play the *"Rain-Sheltering"* mini-game of synchronized movements.
4. Comparisons of Immigrants' contributions	* A Malay village along the river * Supplies and service provisions (i.e. Malays shipbuilders) * Raffles Landing Site / "The Statue of Raffles"	A Malay elder (NPC) acts as a facilitator who helps Players to organize and reflect on the overall information fragments from the gaming experiences (who have they met and their respective contributions to the settlement).	Players unlock a secret virtual document through markerless-AR recognition (natural feature tracking) of a physical feature at this location (The "Statue of Raffles" at the Raffles Landing Site).

6.2.2 Pre-Study

6.2.2.1 Initial Design Themes

Domain knowledge of the learning context (Section 5.2.2.1) and content (Table 5, Column 1) was first drawn by the educational researcher from the academic syllabus (History Syllabus, 2005) and translated into design themes (Table 5, Column 2).

6.2.2.2 Design Considerations for Game Specifications

In line with the context of "The Jackson Plan" (Section 5.2.2.1), the LBG is to be played by a pair of students and each game session would be accompanied by an adult moderator for facilitation (Frohberg, 2006) and safety reasons (Thomas, 2003). Considering potential straying player-movements during actual game runs with children in outdoor environments, the team decided on a single-display groupware (Stewart, Raybourn, Bederson, and Druin, 1998) play mode using one handheld device (Apple iPad2), thus physically co-locating both players in closer proximity to the moderator (teacher). The single-display groupware presentation is intended to help retain children's attention, while facilitating discussions and collaborations between the player-pair (Xu et al., 2008).

Well-designed placements of information in virtual or AR systems where communicative intent is specified by a prioritized list of communicative goals make it possible for the experience of a world that does not exist or one that exists at another time or place (Feiner, MacIntyre, and Seligmann, 1993). Initial gaming concepts are drawn from (Akkerman, Admiraal, and Huizenga, 2009; Martin, 2008; Wither et al., 2010; Dow et al., 2005; Montola et al., 2009; Ju and Wagner, 1997). To enrich the user experience, "mini-games" (Bellotti, Berta, Gloria, and Zappi, 2008) are used as game activity segments at selected prominent locations to feature novel interaction(s), i.e. (Ballagas, Kuntze, and Walz, 2008). Mini-games are short simple games that focus the player's attention on a particular item or event during an exploration process of a bigger virtual game world. The activities may bear well-known game models or genres (Montola et al., 2009) but should be immediately playable so that player can focus on the content rather than on learning how to play (Bellotti, Berta, Gloria, and Zappi, 2008). The end deliverable expected of this co-creativity execution was a functional game prototype.

Figure 44. Direct isomorphic-mapping of game to real-world space.

6.2.2.3 Defining Real-World Game Space

"The Jackson Plan" is an actual architectural drawing (Figure 35, Middle/Right), it served as a physical spatial reference to the game space (the direct isomorphic method by Lindley (2005) was applied), albeit only relatively on the corresponding physical real-world area because of architectural changes over the last two centuries (Figure 44 shows the overlay in Google Earth[17]). This mapping process influenced game design (game event placements in Section 5.2.2.2, Step 6). A quick "bodystorming" (Oulasvirta, Kurvinen, and Kankainen, 2003) session was conducted at the proposed game site by the researchers to confirm that the selected HAR-technology deployment spots were "usable" (i.e. ensuring good GPS reception and physical features were not too difficult to locate for first-timers, etc.). The associated limitations surrounding the technological features in the last section were determined or at least identified during the evaluative session, i.e. image-based AR recognition/ location tracking stabilities were tested at different

[17] http://earth.google.com

times of the day. This technique has been found to be useful for "physical site-sensing" (White and Feiner, 2009), and for "LBG ideations" (Bidwell and Holdsworth, 2006). During the initial conceptualization of the project, there were concerns with the available options for physical AR-feature recognitions (considering sunny outdoor lighting conditions which cameras of handheld devices might not operate well under), and with possible location inaccuracy (GPS) issues as the area is along a river with nearby modern skyscrapers.

6.2.3 "The Jackson Plan" Game Design (Part 2)

The Pre-Study (Section 6.2.2) was completed ahead by the host group that consisted of three researchers from: **1) Technology *(rT)***, **2) Design *(rD)*** and **Social Science (Education) *(rE)*** backgrounds respectively as soon as it was confirmed that two SP students would be working with the team in dedicated artist roles (2D art and game design) as their ITP assignment (Section 6.2.1), noting however that only one student (the one on 2D art) was originally assigned to work on "The Jackson Plan". It was intended for this student-artist to take on both art and game design tasks, given that students undergo the same foundation courses in SP. The remaining parts of this section are: the knowledge empowerment process (Section 6.2.3.1), co-creation group activities (Section 6.2.3.2), the co-assignment (Section 6.2.3.3), individual and domain sub-group contributions (Section 6.2.3.4), and the iterative design process (Section 6.2.3.5). Preproduction and production documentations, design notes, logs, and e-mail/oral communication transcripts are used to present this case study.

6.2.3.1 Knowledge Empowerment and Access

During the first week, the team introduced AR technology overviews to both **Student-Artist A *(SA)*** the 2D Artist, and **Student-Artist** *B* ***(SB)*** the Game Designer. Their roles were predetermined ahead in Section 6.2.1. Both of the students had no prior working/industry experience. Although *SB* was initially assigned to another less work-intensive project that was led by another researcher colleague (not in “The Jackson Plan” group), the researcher team felt that the session might be interesting to him and hence included him in the remaining group ideation activities of this section and Section 6.2.3.2. It would be explained later how *SB* eventually became actively involved with mini-game design work for the project. The following topics were covered using still images, videos and selected research papers during the introduction: “History of Mobile AR” (Wagner, 2009), features that can be used in HAR game design (Chang et al., 2011; Xu et al., 2011), common HAR challenges (from the pre-study and (Broll, Ohlenburg, Lindt, Herbst, and Braun, 2006)), and the researcher team provided examples such as “Spirit Camera” (Nintendo, 2012) and Games Alfresco's list of AR games (Inbar, 2009). Common technological constraints were highlighted along the way (i.e. such as those covered in Section 1.4). The students were allowed to have “hands-on” physical plays with HAR software-loaded devices (Apple iPad2/3rd Gen. and iPhone4S) during working hours. This turned out to be their first exposure to AR (actual interactions with the technology). Next, the researcher team introduced “The Jackson Plan” (Section 5.2.2.1) using the history textbook (CPDD, 2007), initial design themes (Section 6.2.2.1), and images taken during the bodystorming session (Section 6.2.2.3). The students were encouraged to interact with the researcher team.

6.2.3.2 Practice-based Co-Creation Group Activities

Narrative and Game Concept Abstractions

A "Post-Its" session led by *rD* was used to discuss and ideate the game structure of the adventure-styled LBG by the group, colored squares represented different game event segments, i.e. scene chapter points including transitions between geo-specific panorama artwork and HAR feature modes (orange), within-scene screen transition points (yellow), dialogues for Non-Playable Characters/NPCs (pink), and requirements for mini-games with HAR features (blue), as in (Figure 45, Left). Player-actions and interactions for triggering in-game transitions were discussed and denoted on the individual Post-Its, forming the narrative's overall flow in (Table 5, Column 3) that was used in the mini-games' development (Section 6.3.1, Mini-Games).

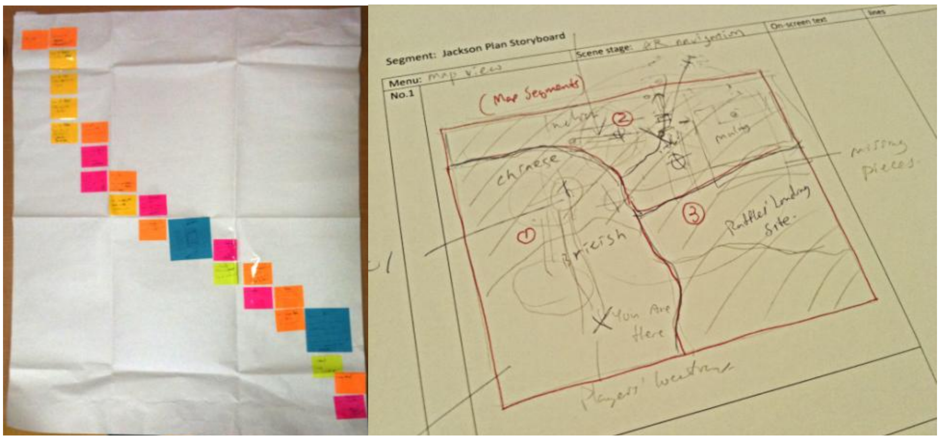


Figure 45. (Left): Game structure for "The Jackson Plan", (Right): Game area / map segmentation discussion.

The game features an in-game map that "scaffolds" to reveal new destinations using extended map pieces with game progress. It is used in conjunction with GPS navigation to guide players to the predesignated locations that are to be explored (visited), as players would learn during the game. As such, the game area was divided into three segments (Figure 44, Right) in preparation for its art development (Section 6.3.2.4, 2D Art Development). A total of 7 scene events excluding the game's opening title were created from the game structure (Figure 45, Left) and sequentially distributed across the layout of the game area from Section 6.2.2.3 in the order of historic relevance to establish the user experience overview as in (Figure 37). The resultant outputs of this section allowed the team to have the necessary references to respectively work on from thereon, either individually or in domain sub-groups (Section 6.2.3.4). The team also compiled a report for a content review by an external education researcher with teaching experiences. A master schedule that was negotiated between the group's researchers was drafted at the beginning of Week 2 based on the outstanding required tasks for the project: a detailed narrative script (developed mainly by *rE* and edited by *rD,* Section 6.2.3.4, Narrative script refinement), game designs for the mini-games (by *SA*, Section 6.2.3.4, Mini-Games' developments), art assets to be produced (by *SA*, Section 6.2.3.4, 2D art development), preparations of information architecture (by *rD*, described in Section 6.2.3.4, Interaction flow and coordination), key concept sketches and overall coordination (by *rD,* Section 6.2.3.4, Interaction Flow and Coordination), and system development (by *rT,* Section 6.2.3.4, System Development). *SB* had not been assigned any individual work tasks at this point as he was left to work on the project under the original assignment.

6.2.3.3 The Co-Assignment

Towards the end of Week 2, the researcher team co-assigned *SB* (who was at that time working on another project) to the designing of the mini-games in order to keep up with the schedule. Progress had been pressured mainly by the extra time that the team took with *SA* to determine the visual style and detail that could be achieved in the given time for the art assets (the whole process took longer than anticipated).

6.2.3.4 Individual and Domain Sub-Group Contributions

This section describes the work that was completed by individual team members or domain sub-groups.

Narrative Refinement (Script)

The final narrative script was prepared by *rE* using (Table 5), and edited by *rD* for context continuity in the game design.

Mini-Games' Developments

As a result of the co-assignment (Section 6.2.3.3), *SB* worked on initial conceptualizations for the two mini-games' designs from the discussions of the "Post-Its" session (Section 6.2.3.2, Narrative and Game Concept Abstractions). His specific directions from *rD* were that although not a requirement, mini-games should preferably include HAR features or interactions. *SB* later directly worked with *SA* to assess the design requirements for the mini-games' art assets (2D graphics).

2D Art Development

The required artwork to be completed by *SA* comprised of the following – artwork for 7 game characters (2 poses each), 12 scene backgrounds, 17 mini-games' UI elements, 5 objects and 1 background for the panorama artwork (using Figure 46 to pre-visualize the required scenes), 1 in-game map (Figure 36), and 1 splash screen (main title page for the game). Historical visual references were compiled by *rD* and *rE* from various public sources, including the National Archives of Singapore[18].

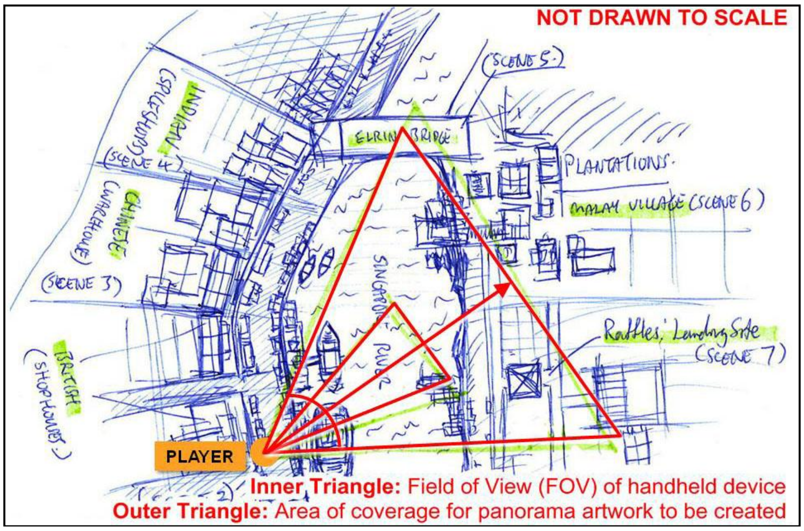


Figure 46. Conceptual overview.

Interaction Flow and Coordination

rD prepared an interaction flow diagram (Figure 47) and a conceptual visualization overview (Figure 46) from the group's discussions (Section 6.2.3.2) that guided requirements for the mini-games' developments and the panorama artwork (Section 6.2.3.4). It

[18] http://www.nhb.gov.sg/nas/

also charted the information flow to aid system development (described in the next paragraph).

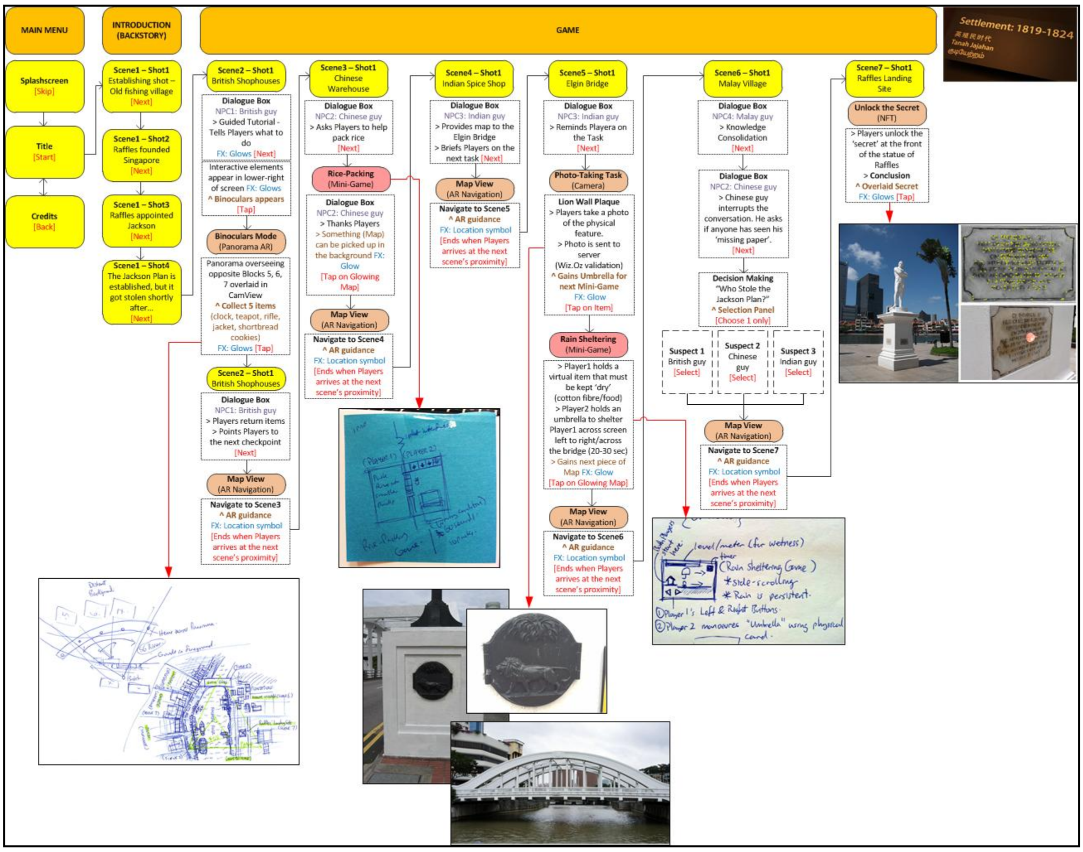


Figure 47. Interaction flow diagram for "The Jackson Plan."

System Development

rT developed the system for the LBG based on the discussed requirements in Section 6.2.3.4 (Interaction Flow and Coordination) or as in Figure 47. The selected platform for "The Jackson Plan" was the Apple iPad2 in consideration of the following features – a relatively large screen, GPS, gyroscope, camera, and sufficient rendering power for vision-based markerless-AR experiences. "Cocos2d"[19] was used to structure the multi-functional system architecture of the adventure game that included character dialogues, game scenes, screen options,

[19] http://www.cocos2d-iphone.org (Last retrieved: 1 November 2012)

and in-game mode switches of the LBG. When it became evident that visual HAR features would be used as designed activities (through Section 3.4.2), "Qualcomm Vuforia" ("Developing with Vuforia," n.d.) was included to embed markerless-AR support (AR library). As *SB* was keen to be involved with system development work, he helped out in "LUA" scripting tasks for the game scenes (sequencing events and character dialogues).

6.2.3.5 Iterative Design

Group meetings although regular (up to twice a week), were usually impromptu due to evolving project needs. During the 6 weeks that passed, there were several instances of interdependencies in the packed activities of Sections 6.2.3.2, 6.2.3.3 and 6.2.3.4 that demanded immediate iterative cycles of feedback and revisions on issues and ideas that surfaced, i.e. the group discussed *SA*'s artwork and *SB's* mini-game ideas to combine narrative and collaborative elements into them (Table 5, Column 4), which were then used to refine the narratives (Section 6.2.3.4).

6.3 Design Outcomes

This section reports the design outcomes of *SA* and *SB* for the respective tasks of art development and game-design work.

6.3.1 First Design Iteration (Concepts)

Art Development (Initial Sketches)

Conceptual sketches were initially proposed by *SA* (Figure 48), which required the approval of *rD* (first on the visual element selections and compositions, and later on colors and shading, etc.). *rE* advised on the possible inclusions of appropriate educational themes into the artwork (i.e., Table 5, Column 2). Several of the early conceptual sketches were reworked numerous times in **Week 2**, causing the team's overall progress to fall back slightly. By **Week 3** (which was halfway into the 6-week ITP), *rD* asked *SA* to instead prepare a self-projected task schedule while factoring the remaining work balance and the number of working days left (which was actually only 17 days).

Figure 48. Student A's artwork - Sketches and colored backgrounds.

Mini-Games

SB produced 10 mini-game ideas in two days. A few of these ideas had screenshots of existing games to illustrate specific game mechanics or HAR features. The researcher group selected the following two initial ideas to develop further from Section 6.2.3.5,

Mini-Game 1 - Players play a Siamese worker to put the sacks of rice on the shelves of the storeroom by dragging and dropping the rice sacks.

- *Scoring is based on time.*
- *The other player can perhaps control a piece of cloth using an AR marker to wipe off the kerosene before the first player is able to place a rice sack on the shelf.*

Mini-Game 2 - Players assume the role of a worker who has to build a bridge to cross the Singapore River. There are bricks and support pillars that can be used to construct a bridge. The bridge would not hold together if there are no support pillars. The bricks would not hold if no cement is applied (Figure 49).

- *The first player is only able to move left and right to pick up objects to construct the bridge.*
- *Players can only complete the mini-game if they get to the other end of the bridge. There is no scoring system.*
- *Using an AR marker, the second player is able to determine the positioning of the objects. It has to be close to the first*

character in the game. A button is used to confirm the positioning of the object.

- *If Players try to walk across without completing the bridge, they would fall into the river and respawn at the starting point.*

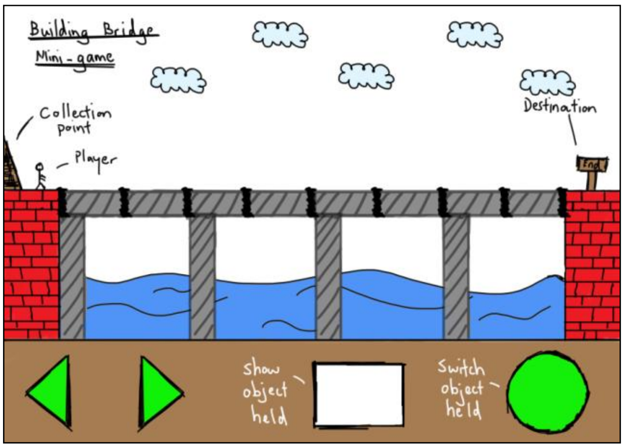


Figure 49. Student B's initial concept for Mini-Game 2.

Figure 50. Reflecting the Past in Present
(Source: Lim Kheng Chye's Collection, archstudio@pacific.net.sg).

6.3.2 Second Design Iteration (Low Fidelity Prototype)

Both the mini-games were revised further by the researcher team to structure player-collaborations through synchronous game activities with embedded contextual information from Table 5. Given the target user audience (secondary school students) and the intended use site (urban outdoors), the team sought for an easy and uncomplicated interaction design for these mini-games (i.e. Rules must be simple and intuitive enough such that it would be possible for players to win at the first try). The use of physical AR card markers (Figure 50) was included to enrich player-interactions while player-scorings were combined from both featured mini-games.

An offline low fidelity prototype was created in **Week 4** with the inputs of *SA's* artworks (temporary proxies were used for on-going or incomplete parts), and *SB's* reworked mini-game ideas into the system by *rT* that allowed for the independent play-testing of the two mini-games and the panorama artwork feature by our group members and other colleagues in the lab (Figure 51). Playtesting and preliminary feedback from testers allowed *SB* to propose how the mini-games' interactions should be tweaked and balanced (in discussions with *rD* and *rT*) as the mini-games were initially in an "unconstrained" state to explore limitations and extents of interactions and game mechanics. Art development by *SA* continued (Figure 48, Bottom).

Figure 51. Low fidelity prototype (left to right): "Mini-Game 1", "Mini-Game 2", and "Panorama Artwork" feature.

Modified Mini-Game 1 ("Rice-Packing"): In *SB*'s initial revision (Figure 52, Left) the physical-card holding player's position was on the right, which was swapped after a group meeting because of the intended orientation of the in-built camera of the handheld device (top left corner from a user's left hand when the device is held up, i.e. as in Figure 53 (Right). The number of physical card-orientation options was also reduced from three to two as it was found during playtesting that a complete 180-degree card-rotation gesture was unpleasant and unintuitive to perform repeatedly without obstructing the camera's view. Players collaboratively pack sacks of rice in corresponding sequential steps for "packing" (Player 1, using on-screen UI to perform sequentially-ordered moves) and "catching" (Player 2, using physical card marker orientations to trigger appropriate "basket" changing and catch falling colored-sacks in time). Only complete cycles of the two players' actions count towards scoring. "Mispacked sacks" (those that have been packed using broken sacks) are to be thrown into the virtual trashcan (Figure 39, Left: Mini-Game 1; Figure 52, Left).

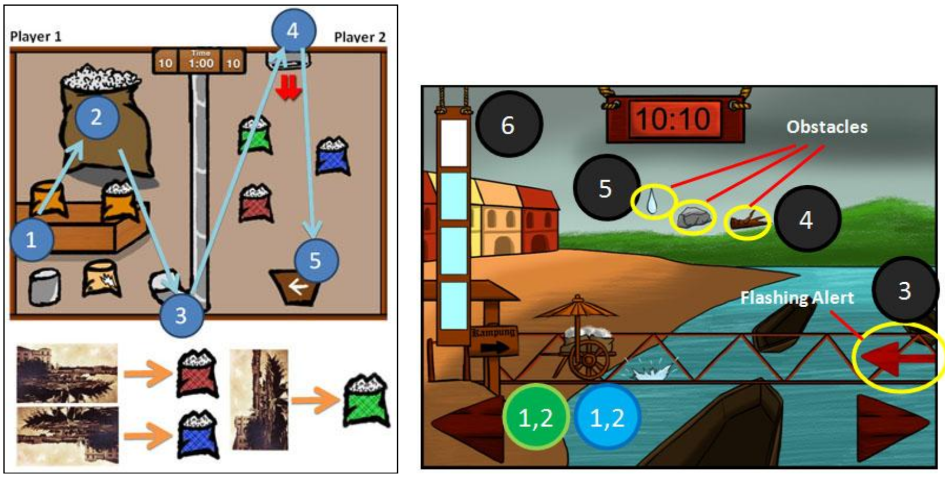


Figure 52. Student B's revised concepts:
(Left) Mini-Game 1, (Right) Mini-Game 2.

Modified Mini-Game 2 ("Rain-Sheltering"): (Figure 52, Right) shows *SB*'s initial revised concept that depicts synchronous player-movements (numbered 1 to 2 in green and blue circles) and random obstacles (winds, twigs/stones, and rain as numbered in black circles 3 to 5) would hinder players' movement efforts. The meter-bar (black circle 6) indicates the wetness of the cotton, having been exposed to rain if left unsheltered. Player 2 (using a physical AR card marker to control a virtual umbrella) is required to shelter Player 1 (using on-screen buttons to maneuver a virtual cart of cotton stock) to keep the cotton dry while crossing the obstacle-filled bridge together.

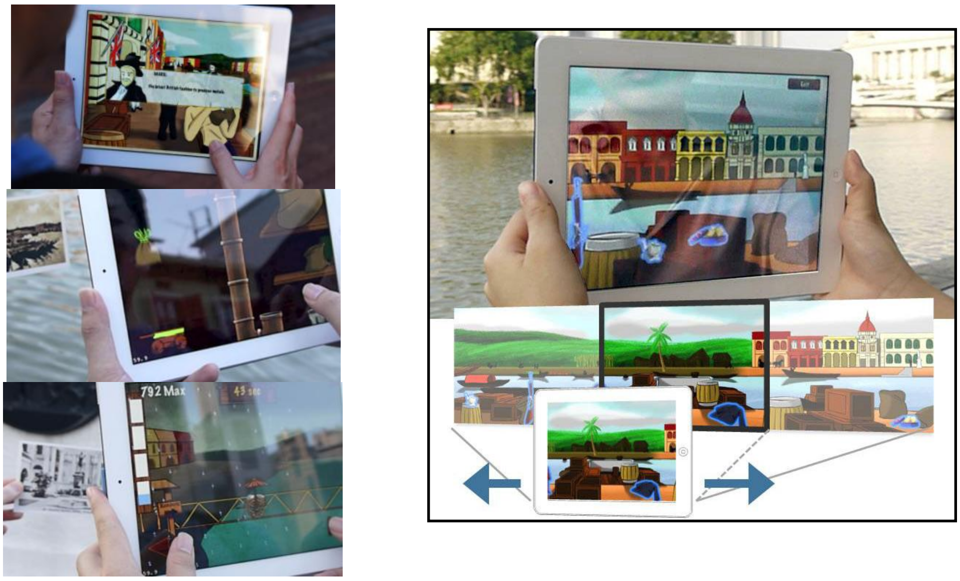


Figure 53. (Left) "The Jackson Plan",
(Right): 180º geo-registered panorama artwork feature.

6.3.3 Third Design Iteration (Refined Prototype)

In line with his own schedule, *SA* spent the last few days of the remaining ITP period on artwork refinements. *SB* by this time had completed his tasks for "The Jackson Plan", and was working on another project. For the remaining game balancing tasks, interactions for the two mini-games' were fine-tuned and mapped to constrain parameters by *rT*. In Mini-Game 2 for example, detected physical AR card movements for Player 1's virtual umbrella movements have been constrained to the horizontal axis, i.e. vertical card translations (movements) are ignored. Through playtesting of the low fidelity prototype, the group found that this constrain eased the control of an on-screen virtual element using a physical gesture. Geo-location service was linked up with game events to complete the prototype (Figure 53). The researcher team only managed to conduct a field trial with the refined prototype after the students' ITP.

6.4 Reflections

The outcomes of practice-led research can be valuable to others who are pursuing the same track (Edmonds and Candy, 2010). In this study, details on the experiences of working with student-artists to develop an LBG using AR as an evolving technology (Barba et al., 2012; Olsson and Salo, 2012) have been shared (processes, decisions and outcomes). While it is easy to differentiate the contributions of artists in conventional practices and mediums of arts (i.e. contemporary, fine, or digital, etc.), technologists have long debated whether their own form of creation is purely technical or whether it can be viewed as an art when an "initial creative spark is fanned into a flame" (Woolford et al., 2010). The author thinks that the same debate is valid when creative artists and designers start to pick up technologies to directly work with, as (Papagiannis, 2011) or *SB* (in a way) did.

6.4.1 Relational Reciprocities

A real project development with industry-like requirements has been shared, where two student-artists generatively worked for most parts of the design process as equal stakeholders. Their inputs and opinions became integral parts of the project's designs. On the last day of the ITP, the students were asked for their opinions of their ITP work experiences. *SA* replied, "It was very tiring", and *SB* responded, "It was fun and interesting". The author will now attempt to review these statements and relate possible causes for them.

Despite being able to complete the planned project in the relatively short span of 6 weeks, several compromises were made. The production schedule for the required artwork was reworked on as visual quality (a highly subjective attribute) had to be balanced with realistic time allocations. *SB*'s co-assignment (Section 6.2.3.3) was actually due to his confession to *rD* that he did not enjoy game-design work, to the extent that he appeared to be stressed over this initial task allocation (observed by *rD*). The schedule that *SA* prepared later seemingly instilled a sense of self-awareness of his own pacing in relation to how others worked, and he did pick up momentum about a week later. It is apparent that *SB* enjoyed his work very much, as he shared ideas and concepts that blended freshly gained knowledge (technological features and/or limitations). Despite also being in a work environment for the first time, he had a curiosity into (HAR) technology that researchers constantly fed into (knowledge empowerment, (Papagiannis, 2011)).

6.4.2 Post-ITP In-depth Interviews with Student-Artists

The researchers conducted a 50-minute in-depth interview with each of the two student-artists to follow up with their views on their ITP experiences in order to answer the following questions:

Q1) What issue(s) did the team face during the project?

Q2) Did our knowledge empowerment methods enable the co-creativity processes that had led to the final design outcomes?

Q3) Did the student-artists feel that a collaboration process had occurred between the researchers and them?

In order to elicit appropriate responses from the subjects to help answer these questions, key guiding questions from (Table 6) were used to direct the interviews. Responses were then transcribed from digital audio recordings of the interview sessions.

Table 6. Guiding questions for in-depth interviews

For Q#	Guiding Question (GQ)
1	Which aspects of the ITP did you like or dislike? (i.e. daily routines, task allocation, schedules)
2	Describe how you learned about AR. Which approach do you think had been the most effective/important for you to learn about AR?
2, 3	Describe your main role(s) and tasks in “The Jackson Plan” project.
1, 3	What challenges did you face when working with the team members?
1, 2	What difficulty(ies) did the team face during the project? How do you think this was eventually resolved?
2, 3	Do you think that we (researchers) had omitted something (during the ITP) that might have helped you learn even more (on AR learning)?

6.4.2.1 Summary of Responses

Student-Artist A

Q1. *SA* listed “communications” as a problem for him and the team. He found it difficult to understand team members (excluding *SB*) at times (“communications bothered me the most”) and often had to probe further on communicated topics. As an example, he described how members would query him on missing, mismatched or individually subjective visual details in initial versions of his artwork that were generated from our group discussions. He saw that the extra time for his rework had impacted the team’s progress (“this caused delays to the team”).

Q2. and Q3. *SA* identified (hands-on) "demonstrations" to be the best approach for him to learn about AR ("I think that it is a better approach than only watching demonstration videos"). He described his exchanges with *SB* to develop artwork for the mini-games and the sharing of his ideas during discussions to be his contributions towards the project, and acknowledged his inputs of ideas during group meetings as being part of the collaboration process that had occurred ("… I provided views on game contexts that were eventually effected as changes (by the team) in the project.").

Student-Artist B

Q1. *SB* did not sense that the team had been experiencing any real troubling issues but mentioned that there were occasional difficulties for him to fully understand the other members (referring to slight differences in language across disciplines). He also felt that (project) changes were effected rapidly. *SB* claimed ownership of the mini-games' designs and game scripting tasks, and included his inputs during the group meetings as one of his contributions to the project through the following transcribed statement:

"I sometimes gave comments during our meetings. In particular these were the occasions when we discussed which (game concepts/types) were better suited for specific locations (referring to the distribution of the game activities across the physical game site). For instance, (I suggested) that some game types might be better suited for certain locations."

He eventually described processes that happened through the collective efforts of the group and exchanges such as "The splitting of the map into 'treasure-map-like' pieces was also something that **we did together**."

Q2. and Q3. - SB successfully recalled and identified all the sources of 'knowledge empowerment' that were supplied to them (both student-artists) - academic research papers, web video examples and actual practical playtesting of games and AR interaction concepts during project development. He also included the "group meetings" as a source of learning for himself. SB attributed that these sources were equally important for him to learn about AR.

6.4.2.2 Interpretations of Responses (Qualitative)

For Q1: The author would like to see if the student-artists had noticed either the co-assignment (Section 6.2.3.3) or rescheduling (Section 6.3.1, Art Development) incidents. To answer this question, they must explicitly identify *SA*'s work progress during the project as the main cause for these events.

Result: Citing personal experiences, both student-artists reported that they had faced communication issues with team members during the case of "The Jackson Plan". It turned out *SA* himself identified that this problem caused delays on his part and had impacted the team's schedule.

For Q2: The author would like to highlight that "knowledge transfer" (from the researchers) had enabled the student-artists to work with AR media. To answer this question, the student-artists must associate or recognize that their self-identified areas of work as contributions to the group-based AR design activities, and final outcomes.

Result: The student-artists recognized and related their own respective inputs (work and ideas) as part of the project's AR design and execution processes.

For Q3: To answer this question, the student-artists must describe some sense of mutual exchanges of work and ideas between themselves and the other team members that had contributed to the project's design processes and final outcomes.

Result: Both the student-artists cited their contributions of ideas in several of the group-based activities (discussions, meetings, actual design processes and playtesting sessions).

6.5 Review of Study

In this case study, the author sought to create a learning experience of representing "living in the past" in the historical context of "The Jackson Plan" that would allow a pair of players to collaboratively "interact" with contextual information at given points of location-induced opportunities of interactions during gameplay. Situated contexts that are exemplified through storification (linear narratives) and the consideration of technological limitations seem to be able to justify aspects of design attributes for the location-based HAR game.

The study presents the design method that is used to translate theoretical knowledge requirements (Section 5.2.1) and how the game model is applied in practice by employing the appropriate design strategies (Feineret al., 1993). Practice-based research in arts and sciences (technology) is always propagated by a highly responsive and iterative exchange where new insights are quickly fed back into the development process to foster the co-evolutionary processes that happen in tandem within the collaboration (Edmonds and Leggett, 2010) for all the parties involved. Technology use then yields new answers that may lead to the transformation of existing forms and traditional practices across disciplines. Ensuring that materials from every participant are usable is a major challenge in a co-creativity process and was an issue in this study. Working with student-artist collaborations and interdisciplinary design groups (Figure 54) can however be successful when critical issues are properly identified and addressed despite rapidly evolving and changing project requirements (Ahmed, 2012), which this study can be said to be a witness to.

Figure 54. Co-Creativity fusions.

Chapter 7. Summary of Research

7.1 Limitations and Future Work

Due to the various challenges of designing, developing and evaluating an actual AR prototype, there are several limitations in the presented work,

1. This research has only focused on one of the four design possibilities with the proposed game model (availability of both location-based services and collaboration features as the “game type”; refer to Section 5.2.1) to provide initial validity to the proposed model and framework. More games or game-like activities will need to be designed and evaluated in order to further critique and revise the model.

2. The game model is grounded only a single learning theory. Exploring multiple theories in a knowledge domain may be a possible direction with the maturing of the game model after (1).

3. Game genres and narratives as containers for structuring game experiences and designed activities are heavily aligned to physical locations and contexts (Olsson and Salo, 2012), as Chapters 5 and 6 have shown. A linear narrative structure that is set in an adventure game setting has been chosen in line with the intended travel path to be navigated by the player in “The Jackson Plan” experience. Future work with the game model should try to relate game genre selections to specific game experiences and physical play activities. A non-linear approach may be explored as well so that social and serendipitous information discovery can be integrated (MacIntyre et al., 2001).

4. An aspect of video game design is to teach new players how to play. Although "The Jackson Plan" features in-game tutorials to guide players through the various game and HAR mechanics, the tutorial feature has not been explicitly studied for its effects on player engagement and media learnability. Andersen et al.'s (2012) study has found that tutorials may not be justified for games with mechanics that can be discovered through experimented and that tutorials did not significantly improve player engagement.

7.1 Implications and Conclusion

AR is a new medium where conventions, practices and user expectations are currently still evolving (MacIntyre et al., 2001; Papagiannis, 2011; Thomas, 2012) despite its first inception was in the 60's, and the large number of studies that have accumulated over the last two decades (Schmalstieg, Langlotz. And Billinghurst, 2011). New consumer digital devices, camera-equipped handheld devices in particular that can be "plugged" into the smart ecosystem can now instantly deliver synthetic digital information through locations, contexts and other ambient sensory apparatus as augmented experiences in blended virtual and physical worlds. Since HAR competes with many mobile and location-based services in the acquisitions of surrounding digital information, content is a critical design factor that has to authentically take advantage of AR instead of merely representing aggregated web services (Olsson and Salo, 2012). Devices such as Google's upcoming "Project Glass"[20] will only continue to revolutionize the way forms and

[20] https://plus.google.com/+projectglass

experiences are being designed for users of AR and rely on the “foundations of the conventions of the relevant earlier media forms” to guide design and to manage user expectations and interests, which are often fed by imagination and pop culture (MacIntyre et al., 2001). Like other early predecessors of digital media platforms (i.e. desktop multimedia, World Wide Web, PC computer games, social media, etc.), there lies an inclination for games or gamified experiences to follow closely with the evolutions of technological developments but its users tend to hold the expectations of earlier media forms, as the extensive literature review in this thesis have shown (Chapters 2 and 3). Led by contexts, the fluid blending of the virtual and physical worlds makes AR a unique medium that allows rich dramatic possibilities do not exist in any other medium (MacIntyre et al., 2001). The “fast-paced technological integration” (Linder and Ju, 2012) with information spaces is also what makes designing HAR game design different from traditional game design, giving designers tremendous creative space for explorations with new-found capabilities but it also introduces distinct issues that are largely related to uncertainties with technologies. This thesis focuses on exploring this specific design space.

A game design methodology that is based on the translations of a grounded knowledge domain via a learning theory with traits of technologies into meaningful knowledge-based design elements and activities for games is presented in this thesis. Consisting of a framework and a model, a situated game prototype has been created in an interdisciplinary setting using one of the design possibilities with the model and then evaluated whether intended communication goals of the designed game media have been met in the study.

One emphasis of this thesis is to invoke in non-technical designers, an understanding with how to better design and conceptualize using HAR technology by witnessing its past, present and possible futures. Reflecting on practical design practices has helped to reveal insights and lessons in the new media which the author concludes to be valuable to designers to relate to the critical issues being discussed on both theoretical and practical levels. Lastly, the methodology aims not only to inform designers with an independent design process for HAR game media and experiences, but also to be better coordinated in interdisciplinary environments for such complex technology projects.

References

Ahmed, S. U. (2012). Developing Software-Dependent Artwork: Artist and Software Developers' Collaboration. *Leonardo, 45*(1), 92-93.

Akkerman, S., Admiraal, W., and Huizenga, J. (2009). Storification in History education: A mobile game in and about medieval Amsterdam. *Computers & Education, 52*(2), 449-459.

Andersen, E., O'Rourke, E., Liu, Y.-E., Snider, R., Lowdermilk, J., Truong, D., Cooper, S., and Popovic, Z. (2012). *The impact of tutorials on games of varying complexity*. Paper presented at the ACM Annual Conference on Human Factors in Computing Systems, Austin, Texas. New York: ACM.

Apple's iPhone 4S price: How much it really costs to make. (2011). Retrieved 1 December 2011 from http://www.dailymail.co.uk/home/moslive/article-2059829/Apples-iPhone-4S-price-How-really-costs-make.html

Azevedo, R., Verona, M., and Cromley, J. (2001). Fostering students' collaborative problem solving with RiverWeb. *Artificial intelligence in education: AI-ED in the wired and wireless future*, 166-175.

Azuma, R. T. (1997). A survey of augmented reality. *Presence-Teleoperators and Virtual Environments, 6*(4), 355-385.

Ballagas, R., Kuntze, A., and Walz, S. (2008). Gaming tourism: Lessons from evaluating rexplorer, a pervasive game for tourists. *Pervasive Computing*, 244-261.

Barba, E., MacIntyre, B., and Mynatt, E. D. (2012). Here We Are! Where Are We? Locating Mixed Reality in The Age of the Smartphone. *Proceedings of the IEEE, 100*(4), 929-936.

Barba, E., Xu, Y., Maclntyre, B., and Tseng, T. (2009). *Lessons from a class on handheld augmented reality game design*. Paper presented at the 4th International Conference on Foundations of Digital Games, Orlando, Florida.

Bates, B. (2004). *Game design, 2nd Edition.* Thomson Course Technology.

Bellotti, F., Berta, R., Gloria, A. D., and Zappi, V. (2008). *Exploring gaming mechanisms to enhance knowledge acquisition in virtual worlds*. Paper presented at the 3rd International Conference on Digital Interactive Media in Entertainment and Arts, Athens, Greece.

Benford, S., Magerkurth, C., and Ljungstrand, P. (2005). Bridging the physical and digital in pervasive gaming. *Commun. ACM, 48*(3), 54-57. doi: 10.1145/1047671.1047704

Bichard, J.-P., and Waern, A. (2008). *Pervasive play, immersion and story: designing Interference*. Paper presented at the 3rd international conference on Digital Interactive Media in Entertainment and Arts, Athens, Greece.

Bidwell, N. J., and Holdsworth, J. (2006). *Battleship by foot: learning by designing a mixed reality game*. Paper presented at the 3rd Australasian conference on Interactive Entertainment. New York:ACM.

Billinghurst, M., Belcher, D., Gupta, A., and Kiyokawa, K. (2003). Communication behaviors in colocated collaborative AR interfaces. *International Journal of Human-Computer Interaction, 16*(3), 395-423.

Billinghurst, M., and Dünser, A. (2012). Augmented Reality in the Classroom. *Computer, 45*(7), 56-63. doi: 10.1109/mc.2012.111

Billinghurst, M., Grasset, R., and Looser, J. (2005). Designing augmented reality interfaces. *SIGGRAPH Comput. Graph., 39*(1), 17-22. doi: 10.1145/1057792.1057803

Billinghurst, M., and Kato, H. (2002). Collaborative augmented reality. *Communications of the ACM, 45*(7), 64-70.

Billinghurst, M., Kato, H., and Poupyrev, I. (2001). The MagicBook - moving seamlessly between reality and virtuality. *Computer Graphics and Applications, IEEE, 21*(3), 6-8.

Billinghurst, M., Poupyrev, I., Kato, H., and May, R. (2000). *Mixing realities in Shared Space: an augmented reality interface for collaborative computing*. Proceedings of IEEE International Conference on Multimedia and Expo.

Bloom, B. S. (1956). *Taxonomy of educational objectives: Handbook I: Cognitive domain*. New York: David McKay*, 19*, 56.

Bogost, I. (2007). *Persuasive games: The expressive power of videogames*. Cambridge, MA: MIT Press.

Brockmyer, J. H., Fox, C. M., Curtiss, K. A., McBroom, E., Burkhart, K. M., and Pidruzny, J. N. (2009). The development of the Game Engagement Questionnaire: A measure of engagement in video game-playing. *Journal of Experimental Social Psychology, 45*(4), 624-634.

Broll, W., Lindt, I., Herbst, I., Ohlenburg, J., Braun, A. K., and Wetzel, R. (2008). Toward Next-Gen Mobile AR Games. *Computer Graphics and Applications, IEEE, 28*(4), 40-48.

Broll, W., Ohlenburg, J., Lindt, I., Herbst, I., and Braun, A.-K. (2006). *Meeting technology challenges of pervasive augmented reality games*. Paper presented at the 5th ACM SIGCOMM Workshop on Network and System Support for Games, Singapore.

Brown, J. S., Collins, A., and Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher, 18*(1), 32-42

Bucolo, S., Billinghurst, M., and Sickinger, D. (2005). *User experiences with mobile phone camera game interfaces*. Paper presented at the 4th international conference on Mobile and ubiquitous multimedia, Christchurch, New Zealand. New York: ACM.

Candy, L. and Edmonds, E. (2002). *Modeling co-creativity in art and technology*. Paper presented at the 4th conference on Creativity & Cognition.

Chalmers, M., and MacColl, I. (2003). Seamful and seamless design in ubiquitous computing. *Technical Report Equator-03-005, Equator [Technical Reports]*.

Chang, Y.-N., Koh, R. K. C., and Duh, H. B.-L. (2011). *Handheld AR games - A triarchic conceptual design framework*. Paper presented at the Mixed and Augmented Reality - Arts, Media, and Humanities (ISMAR-AMH), IEEE International Symposium On, Basel, Switzerland.

Cheok, A. D., Goh, K. H., Liu, W., Farbiz, F., Fong, S. W., Teo, S. L., Lu, Y., and Yang, X. (2004). Human Pacman: a mobile, wide-area entertainment system based on physical, social, and ubiquitous computing. *Personal Ubiquitous Comput., 8*(2), 71-81.

Consolvo, S., McDonald, D. W. and Landay, J. A. (2009). *Theory-driven design strategies for technologies that support behavior change in everyday life*. Paper presented at the SIGCHI Conference on Human Factors in Computing Systems. New York: ACM.

Cox, A., Cairns, P., Shah, P., and Carroll, M. (2012). *Not doing but thinking: the role of challenge in the gaming experience*. Paper presented at the ACM SIGCHI Annual Conference on Human Factors in Computing Systems, Austin, Texa. New York: ACM.

Curriculum Planning and Development Division (CPDD). (2007). *From Settlement to Nation, Pre-1819 to 1971*. Singapore: Ministry of Education and Marshall Cavendish. ISBN: 9789814211833

de Sá, M. and Churchill, E. (2012). *Mobile augmented reality: exploring design and prototyping techniques.* Paper presented at the 14th international conference on Human-computer interaction with mobile devices and services (MobileHCI). New York: ACM.

Deterding, S., Sicart, M., Nacke, L., O'Hara, K., and Dixon, D. (2011). *Gamification. using game-design elements in non-gaming contexts*. Proceedings of the 2011 Extended abstracts on ACM SIGCHI Conference on Human Factors in Computing Systems.

Developing with Vuforia. (n.d.). Retrieved 1 November 2012 from Qualcomm Vuforia Developer's website, https://developer.vuforia.com/resources/dev-guide/getting-started

Dickey, M. D. (2005). Engaging by design: How engagement strategies in popular computer and video games can inform instructional design. *Educational Technology Research and Development, 53*(2), 67-83.

Dixon, H., Mitchell, V., and Harker, S. (2004). Mobile phone games: Understanding the user experience *Design and emotion: the experience of everyday things* (pp. 256-261). London, UK: Taylor and Francis.

Dosi, G. (1982). Technological paradigms and technological trajectories: a suggested interpretation of the determinants and directions of technical change. *Research policy, 11*(3), 147-162.

Dow, S., Lee, J., Oezbek, C., Maclntyre, B., Bolter, J. D., and Gandy, M. (2005). *Exploring spatial narratives and mixed reality experiences in Oakland Cemetery.* Paper presented at the 2005 ACM SIGCHI International Conference on Advances in computer entertainment technology, Valencia, Spain. New York: ACM.

Duh, H. B.-L., Chien-Hsu, C., Su, C. C. C., and Koh, R. (2009). An intuitional interface for invocation of Chinese painting. Proceedings of *Mixed and Augmented Reality - Arts, Media and Humanities* (ISMAR-AMH). IEEE International Symposium on.

Duke, R. D. (1980). A Paradigm for Game Design. *Simulation and games, 11*(3), 364-377.

Edmonds, E. and Candy, L. (2010). Relating Theory, Practice and evaluation in Practitioner research. *Leonardo, 43*(5), 470-476.

Edmonds, E. and Leggett, M. (2010). How Artists Fit into Research Processes. *Leonardo, 43*(2), 194-195.

Eishita, F. Z. and Stanley, K. G. (2010). *THEEMPA: simple AR games using layar*. Paper presented at the International Academic Conference on the Future of Game Design and Technology, Vancouver, British Columbia, Canada.

Ermi, L. and Mäyrä, F. (2005). *Fundamental Components of the Gameplay Experience: Analysing Immersion*. Proceedings of the DiGRA conference Changing views: worlds in play.

FDIS, I. 9241–210: 2009 (2009) Ergonomics of human system interaction-Part 210: Humancentred design for interactive systems. *International organization for standardization, ISO*.

Feiner, S., Macintyre, B., and Seligmann, D. (1993). Knowledge-based augmented reality. *Commun. ACM, 36(7)*, 53-62.

FitzGerald, E. (2012). Towards a theory of augmented place. *Bulletin of the Technical Committee on Learning Technology, 14*(4), 43-45.

Frohberg, D. (2006). *Mobile Learning is Coming of Age: What we have and what we still miss*. Paper presented at the DeLFI 2006: Die 4, e-Learning Fachtagung Informatik der Gesellschaft, für Informatik, Darmstadt.

Gaver, W. W. (1991). *Technology affordances*. Paper presented at SIGCHI conference on Human factors in computing systems: Reaching through technology.

Grubert, J., Morrison, A., Munz, H., and Reitmayr, G. (2012). *Playing it real: magic lens and static peephole interfaces for games in a public space*. Paper presented at the 14th ACM SIGCHI International Conference on Human-Computer Interaction with Mobile Devices and Services (MobileHCI). New York: ACM.

Gu, Y. X., Chen, V. H. H., Koh, R. K. C., and Duh, H. B.-L. (2010, 5-7 July 2010). *Facilitating Learning Interests Through Mobile Information Visualization.* Paper presented at the Advanced Learning Technologies (ICALT), 2010 IEEE 10th International Conference on.

Güven, S. and Feiner, S. (2006). *Visualizing and navigating complex situated hypermedia in augmented and virtual reality*. Paper presented at the Mixed and Augmented Reality. IEEE/ACM International Symposium on.

Hand, C. (1997). A survey of 3D interaction techniques. *Computer Graphics Forum, 16*(5), 269-281.

Hayes, A. F., Preacher, K. J., and Myers, T. A. (2010). *Mediation and the estimation of indirect effects in political communication research*. New York: Routledge.

Hazas, M., Scott, J., and Krumm, J. (2004). Location-aware computing comes of age. *Computer, 37*(2), 95-97.

Henrysson, A. and Billinghurst, M. (2007). *Using a mobile phone for 6 DOF mesh editing*. Paper presented at the 7th ACM SIGCHI New Zealand Chapter's International Conference on Computer-Human Interaction: Design Centered HCI, Hamilton, New Zealand.

Henrysson, A., Billinghurst, M., and Ollila, M. (2005). *Face to face collaborative AR on mobile phones.* Paper presented at the Mixed and Augmented Reality. Fourth IEEE and ACM International Symposium on.

Herrington, J. and Oliver, R. (1995). *Critical Characteristics of Situated Learning: Implications for the Instructional Design of Multimedia*. Paper presented at the ASCILITE '95.

Hill, J. R. and Hannafin, M. J. (2001). Teaching and learning in digital environments: The resurgence of resource-based learning. *Educational Technology Research and Development, 49*(3), 37-52.

History Syllabus. (2005). Retrieved 10 December 2011 from http://www.moe.gov.sg/education/syllabuses/humanities/files/history-lower-secondary-2006.pdf (Unit 8, Pg. 13)

Hong, H., Jeong, H. Y., Arriaga, R. I., and Abowd, G. D. (2010). *TriggerHunter: designing an educational game for families with asthmatic children*. Paper presented at the 28th of the International Conference Extended Abstracts on Human Factors in Computing Systems, Atlanta, Georgia.

Huynh, D.-N. T., Raveendran, K., Xu, Y., Spreen, K., and MacIntyre, B. (2009). *Art of defense: a collaborative handheld augmented reality board game.* Paper presented at the 2009 ACM SIGGRAPH Symposium on Video Games, New Orleans, Louisiana

Inbar, O. (2009). Your Favorite Augmented Reality Games Of All Time. Retrieved: 1st November 2012 from http://gamesalfresco.com/2009/06/27/your-favorite-augmented-reality-games-of-all-time

Jegers, K. (2007). Pervasive game flow: understanding player enjoyment in pervasive gaming. *Comput. Entertain., 5*(1), 9. doi: 10.1145/1236224.1236238

Jimenez Pazmino, P. and Lyons, L. (2011). *An exploratory study of input modalities for mobile devices used with museum exhibits.* Paper presented at the ACM SIGCHI Annual Conference on Human factors in computing systems. New York: ACM.

Jones, S. (2011). A Systems Basis for New Media Pedagogy. *Leonardo, 44*(1), 88-89.

Ju, E. and Wagner, C. (1997). Personal computer adventure games: their structure, principles, and applicability for training. *SIGMIS Database, 28*(2), 78-92. doi: 10.1145/264701.264707

Kato, H. and Billinghurst, M. (1999). *Marker tracking and HMD calibration for a video-based augmented reality conferencing system.* Paper presented at the Augmented Reality (IWAR '99). 2nd IEEE and ACM International Workshop on.

Kirkley, S. and Kirkley, J. (2004). Creating next generation blended learning environments using mixed reality, Video Games and Simulations. *TechTrends, 49*(3), 42-53. doi: 10.1007/bf02763646

Klopfer, E. (2008). *Augmented learning: research and design of mobile educational games*: The MIT Press.

Koh, R. K. C., Duh, H. B.-L., Chen, C.-H., and Wong, Y.-T. (2012). *Co-Creativity Fusions Interdisciplinary Augmented Reality Game Developments*. Paper presented at Mixed and Augmented Reality - Arts, Media, and Humanities (ISMAR-AMH). IEEE International Symposium On.

Koh, R. K. C., Duh, H. B.-L., and Gu, J. (2010). *An integrated design flow in user interface and interaction for enhancing mobile AR gaming experiences.* Paper presented at the Mixed and Augmented Reality - Arts, Media, and Humanities (ISMAR-AMH), IEEE International Symposium On.

Krathwohl, D. R. (2002). A revision of Bloom's taxonomy: An overview. *Theory into practice, 41*(4), 212-218.

Krathwohl, D. R., Anderson, L. W., and Bloom, B. S. (2001). *A Taxonomy for Learning, Teaching, and Assessing: A Revision of Bloom's Taxonomy of Educational Objectives*: Longman.

Kuikkaniemi, K., Turpeinen, M., Salovaara, A., Saari, T., and Vuorenmaa, J. (2006). *Toolkit for user-created augmented reality games*. Paper presented at the 5th International Conference on Mobile and Ubiquitous Multimedia, Stanford, California.

Lave, J. and Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*: Cambridge University Press.

Li, D. D. and Lim, C. P. (2008). Scaffolding online historical inquiry tasks: A case study of two secondary school classrooms. *Computers & Education, 50*(4), 1394-1410. doi: 10.1016/j.compedu.2006.12.013

Linder, J. and Ju, W. (2012). *Playable character: extending digital games into the real world*. Paper presented at the ACM SIGCHI Annual Conference on Human Factors in Computing Systems.

Lindley, C. A. (2005). *Game space design foundations for trans-reality games.* Paper presented at the ACM SIGCHI International Conference on Advances in Computer Entertainment Technology, Valencia, Spain. New York: ACM.

MacIntyre, B., Bolter, J. D., Moreno, E., and Hannigan, B. (2001). *Augmented reality as a new media experience.* Paper presented at Augmented Reality. IEEE and ACM International Symposium on.

Magerkurth, C., Cheok, A. D., Mandryk, R. L., and Nilsen, T. (2005). Pervasive games: bringing computer entertainment back to the real world. *Comput. Entertain,. 3*(3), 4-4.

Malone, T. W. (1981). Heuristics for designing enjoyable user interfaces: Lessons from computer games. *Human factors in computing systems* (pp. 63-68). New York, NY, USA: ACM Press.

Martin, J. (2008). *Gaming and Reframing Experiences with Place-Based Inquiry*. Paper presented at the International Congress of Qualitative Inquiry, University of Illinois at Urbana-Champaign.

Martin, P. (2011). *Space and place as expressive categories in videogames.* Unpublished doctoral dissertation, Brunel University.

Mason, J. (2002). *Researching your own practice: The discipline of noticing*: Routledge.

Mayer, R. E. (2002). A taxonomy for computer-based assessment of problem solving. *Computers in Human Behavior, 18*(6), 623-632.

Mendenhall, S., Ha, V., Xu, Y., Tillery, P., Cohen, J., Sharp, J., and MacIntyre, B. (2012). *NerdHerder: designing for physical actions in an augmented reality puzzle game*. Paper presented at the International Conference on the Foundations of Digital Games.

Meyer, J., Staples, L., Minneman, S., Naimark, M., and Glassner, A. (1998). *Artists and technologists working together (panel)*. Paper presented at the 11th annual ACM symposium on User interface software and technology, San Francisco, California.

Milam, D. and El Nasr, M. S. (2010). *Design patterns to guide player movement in 3D games.* Paper presented at the 5th ACM SIGGRAPH Symposium on Video Games, Los Angeles, California. New York: ACM.

Milgram P. and F. Kishino. (1994). A taxonomy of mixed reality visual displays. *IEICE Transactions on Information Systems*, vol .E77-D(12*)*, 1321.

Mishra, P. and Koehler, M. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *The Teachers College Record*, *108*(6), 1017-1054.

Montola, M., Stenros, J., and Waern, A. (2009). *Pervasive games: theory and design*. San Francisco, CA, USA: Morgan Kaufmann Publishers.

Morrison, A., Oulasvirta, A., Peltonen, P., Lemmela, S., Jacucci, G., Reitmayr, G., Näsänen, J, and Juustila, A. (2009). *Like bees around the hive: a comparative study of a mobile augmented reality map*. Paper presented at the 27th International Conference on Human Factors in Computing Systems, Boston, MA, USA. New York: ACM.

Mulloni, A. and Wagner, D. *Mobile Phone Augmented Reality*. (2010). Paper presented at 12th ACM SIGCHI International Conference on Human Computer Interaction with Mobile Devices and Services (MobileHCI). New York: ACM.

Mulloni, A., Wagner, D., and Schmalstieg, D. (2008). *Mobility and social interaction as core gameplay elements in multi-player augmented reality*. Paper presented at the 3rd International Conference on Digital Interactive Media in Entertainment and Arts, Athens, Greece.

Nintendo. (2012). Spirit Camera. Retrieved: 1st November 2012 from http://spiritcamera.nintendo.com

Norman, D. (2002). *The design of everyday things*. Basic books.

Olsson, T. and Salo, M. (2012). *Narratives of satisfying and unsatisfying experiences of current mobile augmented reality applications.* Paper presented at the ACM SIGCHI annual conference on Human Factors in Computing Systems. New York: ACM.

Oulasvirta, A., Kurvinen, E., and Kankainen, T. (2003). Understanding contexts by being there: case studies in bodystorming. *Personal and Ubiquitous Computing, 7*(2), 125-134. doi: 10.1007/s00779-003-0238-7

Paelke, V., Reimann, C., and Stichling, D. (2004). *Foot-based mobile interaction with games*. Paper presented at the ACM SIGCHI International Conference on Advances in Computer Entertainment Technology, Singapore. New York: ACM.

Papagiannis, H. (2011). *The role of the artist in evolving AR as a new medium.* Paper presented at the Mixed and Augmented Reality - Arts, Media, and Humanities (ISMAR-AMH). 2011 IEEE International Symposium On.

Park, A. and Jung, K. (2007). Augmented Galaga on Mobile Devices. In K.-C. Hui, Z. Pan, R. Chung, C. Wang, X. Jin, S. Göbel and E. Li (Eds.), *Technologies for E-Learning and Digital Entertainment* (Vol. 4469, pp. 888-897): Springer Berlin / Heidelberg.

Park, A. and Jung, K. (2009). Flying cake: Augmented game on mobile devices. *Comput. Entertain., 7*(1), 1-19. doi: 10.1145/1486508.1486518

Pintrich, P. R., Smith, D., García, T., and McKeachie, W. (1991). A manual for the use of the Motivated Strategies for Learning Questionnaire (MSLQ). *Ann Arbor. Michigan, 48109*, 1259.

Raths, J. (2002). Improving instruction. *Theory into practice, 41*(4), 233-237.

Reddy, M. (2011). *API Design for C++*. Massachusetts: Morgan Kaufmann.

Ritzer, G. (2007). *The Blackwell encyclopedia of sociology*, 3. Malden, MA: Blackwell Pub.

Rosenbaum, E., Klopfer, E., Boughner, B., and Rosenheck, L. (2007). *Engaging students in science controversy through an augmented reality role-playing game*. Paper presented at the 8th International Conference on Computer Supported Collaborative Learning, New Brunswick, New Jersey, USA.

Rust, C., Mottram, J. and Till, J. (2007). *AHRC research review: Practice-led research in art, design and architecture*: Arts and Humanities Research Council.

Salen, K. and Zimmerman, E. (2004). *Rules of play: Game design fundamentals*. Cambridge, MA: The MIT Press.

Saye, J. and Brush, T. (2002). Scaffolding critical reasoning about history and social issues in multimedia-supported learning environments. *Educational Technology Research and Development, 50*(3), 77-96. doi: 10.1007/bf02505026

Schmalstieg, D., Langlotz, T. and Billinghurst, M. (2011). Augmented Reality 2.0. In G. Brunnett, S. Coquillart and G. Welch (Eds.), *Virtual Realities* (pp. 13-37). Springer: Vienna.

Schmalstieg, D. and Wagner, D. (2007). *Experiences with Handheld Augmented Reality*. Paper presented at the Mixed and Augmented Reality (ISMAR). 6th IEEE and ACM International Symposium on.

Schön, D. A. (1983). *The reflective practitioner: How professionals think in action*: Basic books.

Schunk, D. H. (1991). *Learning theories: An educational perspective*: Macmillan Publishing Co, Inc.

Seligmann, D. D. and Feiner, S. (1991). *Automated generation of intent-based 3D Illustrations*. Proceedings of the 18th Annual Conference on Computer Graphics and Interactive Techniques.

Sharples, M., Taylor, J., and Vavoula, G. (2005). Towards a theory of mobile learning. *Proceedings of mLearn 2005, 1*(1), 1-9.

Squire, K. and Jan, M. (2007). Mad City Mystery: Developing Scientific Argumentation Skills with a Place-based Augmented Reality Game on Handheld Computers. *Journal of Science Education and Technology, 16*(1), 5-29.

Squire, K., Jan, M., Mathews, J., Wagler, M., Martin, J., DeVane, B., and Holden, C. (2007). Wherever you go, there you are: Place-based Augmented Reality Games for Learning. In B. E. Shelton and D. A. Wiley (Eds.), *The educational design and use of simulation computer games* (Vol. 2, pp. 265-296). Rotterdam: Sense Publishers.

Stewart, J., Raybourn, E. M., Bederson, B., and Druin, A. (1998). *When two hands are better than one: enhancing collaboration using single display groupware*. Paper presented at the SIGCHI Conference on Human Factors in Computing Systems. New York: ACM.

Sueda, K., Gu, J., Kitazawa, S., and Duh, H. B.-L. (2011). *Micro AR for education: using metaphors for familiar actions*. Proceedings of the ACM SIGGRAPH Asia 2011 Emerging Technologies.

Sutherland, I. E. (1968). *A head-mounted three dimensional display*. Paper presented at the ACM December 9-11, 1968, fall joint computer conference, part I. New York: ACM.

Thomas, B. H. (2003). *Challenges of making outdoor augmented reality games playable*. Paper presented at the 2nd CREST Workshop on Advanced Computing and Communicating Techniques for Wearable Information Playing, Nara, Japan.

Thomas, B. H. (2012). A survey of visual, mixed, and augmented reality gaming. *Comput. Entertain., 10*(3), 1-33. doi: 10.1145/2381876.2381879

Thomas, B., Close, B., Donoghue, J., Squires, J., De Bondi, P., Morris, M., and Piekarski, W. (2000). *ARQuake: an outdoor/indoor augmented reality* *first person application*. The Fourth IEEE International Symposium on Wearable Computers.

Toth, E. E. (2000). *Representational scaffolding during scientific inquiry: Interpretive and expressive use of inscriptions in classroom learning.* Paper presented at the 22nd Annual Conference of the Cognitive Science Society.

Tran, K. N. and Huang, Z. (2007). *Design and implementation of a built-in camera based user interface for mobile games*. Paper presented at the 5th International Conference on Computer Graphics and Interactive Techniques in Australia and Southeast Asia, Perth, Australia.

Valcke, M., De Wever, B., Zhu, C., and Deed, C. (2009). Supporting active cognitive processing in collaborative groups: The potential of Bloom's taxonomy as a labeling tool. *The Internet and Higher Education*, *12*(3), 165-172.

Wagner, D. (2007). *Handheld Augmented Reality*. Unpublished doctoral dissertation, Graz University of Technology, Austria.

Wagner, D. (2009). History of mobile augmented reality. *Communications*, 1-21.

Wagner, D., Pintaric, T., Ledermann, F., and Schmalstieg, D. (2005). *Towards Massively Multi-user Augmented Reality on Handheld Devices Pervasive Computing*. Paper presented at the 3rd International Conference on Pervasive Computing.

Wagner, D., Schmalstieg, D., and Billinghurst, M. (2006). Handheld AR for Collaborative Edutainment. In Z. Pan, A. Cheok, M. Haller, R. Lau, H. Saito and R. Liang (Eds.), *Advances in Artificial Reality and Tele-Existence* (Vol. 4282, pp. 85-96): Springer Berlin / Heidelberg.

Wagner, D. and Schmalstieg, D. (2003). *ARToolKit on the PocketPC platform.* Paper presented at the Augmented Reality Toolkit Workshop. IEEE International.

Weiser, M. (1991). The computer for the 21st century. *Scientific American, 265(3)*, 94-104.

Weiser, M. (1994). *Creating the invisible interface: (invited talk)*. Paper presented at the Proceedings of the 7th Annual ACM Symposium on User Interface Software and Technology.

Wellner, P. (1991). *The DigitalDesk calculator: tangible manipulation on a desk top display*. Paper presented at the 4th Annual ACM Symposium on User Interface Software and Technology.

Wetzel, R., Blum, L., Broll, W., and Oppermann, L. (2011). Designing Mobile Augmented Reality Games. In B. Furht (Ed.), *Handbook of Augmented Reality* (pp. 513-539). New York: Springer.
What is layar? (n.d.). Retrieved 1 November 2012 from Layar, https://www.layar.com/what-is-layar/

White, S. and Feiner, S. (2009). *SiteLens: situated visualization techniques for urban site visits*. Paper presented at the 27th International Conference on Human Factors in Computing Systems, Boston, MA. New York: ACM.

Wither, J., Allen, R., Samanta, V., Hemanus, J., Yun-Ta, T., Azuma, R., Carter, W., Hinman, R., and Korah, T. (2010). *The Westwood Experience: Connecting story to locations via Mixed Reality.* Paper presented at the Mixed and Augmented Reality - Arts, Media, and Humanities (ISMAR-AMH). IEEE International Symposium On.

Wood, D., Bruner, J. S., and Ross, G. (1976). The Role of Tutoring in Problem Solving*. *Journal of Child Psychology and Psychiatry, 17*(2), 89-100.

Woolford, K., Blackwell, A. F., Norman, S. J., and Chevalier, C. (2010). Crafting a Critical Technical Practice. *Leonardo, 43*(2), 202-203.

Xu, Y., Barba, E., Radu, I., Gandy, M., Shemaka, R., Schrank, B., MacIntyre, B., and Tseng, T. (2011). *Pre-patterns for designing embodied interactions in handheld augmented reality games*. Paper presented at the Mixed and Augmented Reality - Arts, Media, and Humanities (ISMAR-AMH). 2011 IEEE International Symposium On.

Xu, Y., Gandy, M., Deen, S., Schrank, B., Spreen, K., Gorbsky, M., White, T., Barba, E., Radu, L., Bolter, J., and MacIntyre, B. (2008). *BragFish: exploring physical and social interaction in co-located handheld augmented reality games*. Paper presented at the 2008 International Conference on Advances in Computer Entertainment Technology. New York: ACM.

Zhou, F., Duh, H. B.-L., and Billinghurst, M. (2008). *Trends in augmented reality tracking, interaction and display: A review of ten years of ISMAR.* Paper presented at the Mixed and Augmented Reality. 7th IEEE/ACM International Symposium on.

Zimmerman, J., Forlizzi, J., and Evenson, S. (2007). *Research through design as a method for interaction design research in HCI*. Paper presented at the SIGCHI International Conference on Human Factors in Computing Systems.

Appendices

Appendix A: Demographics Questionnaire (Study 2)

Appendix B: Instructional Materials (Study 2)

Appendix C: Pre-Test Questionnaire (Study 2)

Appendix D: Post-Test Questionnaire (Study 2)

Appendix E: Learning Achievement Test (Study 2)

Appendix F: Interaction flow for “The Jackson Plan” (Study 3)

Appendix G: Publications

Appendix A: Demographics Questionnaire (Study 2)

DEMOGRAPHICS

Name: ___________________________ Gender: Male / Female

Age: ____________ Class: ____________

Please answer the following questions to the best of your knowledge.

Content

1. Do you have any difficulty in understanding the chapter on "Growth and Development of Singapore as a British settlement before World War II, 1819-1942"? [Yes/ No]

   Reason(s):____

2. How many hours a week do you study history at home? ______hours

Access to Handheld Devices (Mobile Phone/iPad/ Nintendo DS/PSP, etc.)

3. Do you have a mobile phone?

   [ ] Yes – Go to question 4.

   [ ] No – Go to question 5.

4. Is your mobile phone Touch- (Button) [ ] or Keypad [ ]-based?

5. Which of following devices do you own or have access to?

   ☐ Mobile phone
   ☐ Mobile tablets (ex: Samsung Galaxy / Apple iPad)
   ☐ Console (ex: XBOX360, PS3), please specify: _______

6. What do you use your handheld device for? (Tick all that apply)

☐ Short Text Messaging (SMS)
☐ Project Work
☐ Check real-time information
☐ Playing games
☐ Audio Recording
☐ Voice calls
☐ Music Player
☐ Photo Taking
☐ Data storage medium
☐ Reading E-books

☐ Others (please specify):____

Personal Gaming Experiences

7. Do you like video, computer, mobile or any handheld device games? [Yes/No]

8. How often do you play games?

☐ Everyday ☐ Weekly ☐ Monthly ☐ Others: ________

☐ I do not play games (Skip the next question)

9. What are three of your favourite game types? (List from 1-3)

☐ Action
☐ Adventure
☐ Role-playing
☐ Simulation
☐ Strategy
☐ Puzzle
☐ Music
☐ Sports
☐ Others________________

10. Do you think that there is any game that can assist you in your learning in school? [Yes/ No]

11. If your answer is "YES" to the previous question, please state the title(s) of the game(s).

____

____

Learning Games

12. Do you think it would be easier for you understand topics on "Growth and Development of Singapore as a British settlement before World War II, 1819-1942" through an outdoor game ? [Yes/ No]

    Reason(s):____

13. If your answer to Question 12. is "YES", please answer the following additional questions:

i. Where do you think a <u>history game</u> should be played? (Tick all that apply)

- ☐ at home
- ☐ in the classroom
- ☐ outside classroom and home
- ☐ others (please specify): ________________________________

ii. Who do you think should be involved in your history game play? (Tick all that apply)

- ☐ classmates
- ☐ friends (not in my class)
- ☐ teacher
- ☐ parents
- ☐ others (please specify): _____________________________________

iii. How many hours <u>per week</u> do you think you should spend playing such a history game?

☐ half an hour	☐ 4 hours
☐ 1 hour	☐ more than 4 hours
☐ 2 hours	
☐ 3 hours	

iv. What other resources do you use to study the history topic apart from your textbook and school worksheets?

Please specify: _______________________________________

Thank you!

Appendix B: Instruction Materials (Study 2)

<u>The Jackson Plan (Outdoor/AR Group)</u>

Introduction

"The Jackson Plan" is an Educational Handheld Augmented Reality (AR) game that is designed to support your understanding of the Singapore Town Plan (a historical event).

Schedule Overview

The gameplay is estimated to 100 minutes. The game venue is situated at the present Boat Quay along Singapore River, where the settlement of Singapore first began. After finishing the gameplay, you will be required to complete 2 questionnaires and answer a few questions about your impression of the game and play experience.

Goal

You are now standing at the Singapore River, where the settlement of Singapore first began. You and your partner are two investigators who love adventures. Both of you are in Singapore in the mid-18th century. Your mission is to find out who stole "The Jackson Plan" and bring the criminal to justice. Along the journey, you will meet people from different places. Please pay attention to what they say and do…it will be the useful information for you. Please carry your iPad device cautiously; it will help you navigate …

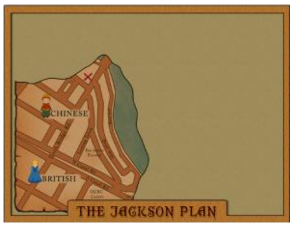


Figure 1. The Navigation Map will tell you where you are.

Figure 2. A look into the past.

Figure 3. Mini-Games: "Rain-Sheltering" (Left) and "Rice-Packing" (Right).

The Jackson Plan (Indoor/Digital Book Group)

Background
"The Jackson Plan" is an educational adventure game that is designed to support your understanding of the Singapore Town Plan (a historical event).

Game Overview
The activity is estimated to take 25 minutes. Through a digital book on the iPad, you will play a short adventure game where the settlement of Singapore first began. After finishing the gameplay, you will be required to complete 2 questionnaires and answer a few questions about your impression of the game and play experience.

Goal
You are now at the Singapore River, where the settlement of Singapore first began. You and your partner are two investigators who love adventures. Both of you are in Singapore in the mid-18th century. Your mission is to find out who stole "The Jackson Plan" and bring the criminal to justice. Along the journey, you will meet people from different places. Please pay attention to what they say and do…it will be the useful information for you.

Figure 1. A look into the past.

Figure 2. Mini-Games: "Rain-Sheltering" (Left) and "Rice-Packing" (Right).

Appendix C: Pre-Test Questionnaire (Study 2)

[Instructions]

The following questions seek to find out more about your perceptions about the History subject and learning in general. Remember there are no right or wrong answers. Answer as accurately as you can use the scale below to answer the questions.

If you think the statement is very true of you, circle 5.
If you think the statement is not at all true of you, circle 1.
If you think the statement is more or less true of you, find the number between 1 and 5 that best describes you.

1 In past history classes, I preferred course materials that really challenged me so I could learn new things.

1 2 3 4 5
not at all true of me **very true of me**

2 In past history classes, I preferred course materials that aroused my curiosity, even if it would be difficult to learn them.

1 2 3 4 5
not at all true of me **very true of me**

3 The most satisfying aspect for me in past history classes was trying to understand the history content as thoroughly as possible.

1 2 3 4 5
not at all true of me **very true of me**

4 It is important for me to learn history.

1 2 3 4 5
not at all true of me **very true of me**

5 History is my favourite subject among all the subjects.

1 2 3 4 5
not at all true of me **very true of me**

6 The approach to learn history in past classes was useful for me to learn.

1 2 3 4 5
not at all true of me **very true of me**

7 I like learning history.

1	2	3	4	5
not at all true of me				**very true of me**

8 Understanding history is very important to me.

1	2	3	4	5
not at all true of me				**very true of me**

9 I am confident that I understood the basic concepts that were previously taught in past history classes.

1	2	3	4	5
not at all true of me				**very true of me**

10 I am confident that I understood the majority of the complicated/complex materials that were previously presented by the teacher in past history classes.

1	2	3	4	5
not at all true of me				**very true of me**

11 I am confident that I can perform well in an assessment/test on the topics that were previously taught in past history classes.

1	2	3	4	5
not at all true of me				**very true of me**

12 I am certain that I can understand the relevance of the chapters that were taught in past history classes.

1	2	3	4	5
not at all true of me				**very true of me**

13 When I study history, I would pull together information from different sources, such as lectures, readings and discussions.

1	2	3	4	5
not at all true of me				**very true of me**

14 When reading for history class, I try to relate the material to what I already know.

1	2	3	4	5
not at all true of me				**very true of me**

15 I try to understand the textbook materials in my history class by making connections between the readings and the concepts that are discussed in classes.

1	2	3	4	5
not at all true of me				**very true of me**

16 I try to apply ideas from history-related readings from class activities such as lectures and discussions.

1	2	3	4	5
not at all true of me				**very true of me**

17 Before studying any new history material, I often skim through it to see how it is organized.

1	2	3	4	5
not at all true of me				**very true of me**

18 I try to think through a topic and decide what I am supposed to learn from it rather just reading it over when studying history.

1	2	3	4	5
not at all true of me				**very true of me**

19 When I sit in a history class, I set personal objectives/goals for myself to direct my activities during each study period.

1	2	3	4	5
not at all true of me				**very true of me**

20 When studying history, I often try to explain materials from the chapter to a classmate or a friend.

1	2	3	4	5
not at all true of me				**very true of me**

21 In past history classes, I would try to work with other students to complete assignments.

1	2	3	4	5
not at all true of me				**very true of me**

22 When studying history, I often set aside time to discuss the textbook materials with a group of students from my class.

1	2	3	4	5
not at all true of me				**very true of me**

Appendix D: Post-Test Questionnaire (Study 2)

[Instructions]

After playing "The Jackson Plan", the following questions seek to find out more about your perceptions about History and learning in general. Remember there are no right or wrong answers. Answer as accurately as you can use the scale below to answer the questions.

If you think the statement is very true of you, circle 5.
If you think the statement is not at all true of you, circle 1.
If you think the statement is more or less true of you, find the number between 1 and 5 that best describes you.

1 Time seemed to have stood still or stopped when I was playing "The Jackson Plan".

1	2	3	4	5
not at all true of me				**very true of me**

2 I felt different when I was playing "The Jackson Plan".

1	2	3	4	5
not at all true of me				**very true of me**

3 I lost track of where I was during the game.

1	2	3	4	5
not at all true of me				**very true of me**

4 I felt scared at times when I played "The Jackson Plan".

1	2	3	4	5
not at all true of me				**very true of me**

5 I momentarily felt lost as I played "The Jackson Plan".

1	2	3	4	5
not at all true of me				**very true of me**

6 I think that learning history by playing a game such as "The Jackson Plan" is useful for me to learn.

1	2	3	4	5
not at all true of me				**very true of me**

7 I like learning history.

1	2	3	4	5
not at all true of me				**very true of me**

8 Understanding history is very important to me.

1	2	3	4	5
not at all true of me				**very true of me**

9 I am confident that I have understood the basic concepts taught in "The Jackson Plan".

1	2	3	4	5
not at all true of me				**very true of me**

10 I am confident that I have understood the lesson in "The Jackson Plan" game.

1	2	3	4	5
not at all true of me				**very true of me**

11 I am confident that I can perform well in an assessment or test on this chapter after playing "The Jackson Plan".

1	2	3	4	5
not at all true of me				**very true of me**

12 I am certain that I have mastered the skills that were taught during my "The Jackson Plan" gameplay.

1	2	3	4	5
not at all true of me				**very true of me**

13 When playing "The Jackson Plan", I gathered information from various sources, such as from the in-game story, physical navigation (movements) to different sites, and mini games.

1	2	3	4	5
not at all true of me				**very true of me**

14 When playing "The Jackson Plan", I tried to relate materials that were presented to me to what I already knew.

1	2	3	4	5
not at all true of me				**very true of me**

15 I tried to understand the contents of "The Jackson Plan" by making connections to the history chapter.

1	2	3	4	5
not at all true of me				**very true of me**

16 I will try to apply ideas and concepts from “The Jackson Plan” in other history class activities such as lectures and discussions.

1	2	3	4	5
not at all true of me				**very true of me**

17 Before studying any new history material, I often flip through the content to see how it is organized.

1	2	3	4	5
not at all true of me				**very true of me**

18 When studying history, I would try to think through a topic and decide what I am supposed to learn from it instead of just reading it through.

1	2	3	4	5
not at all true of me				**very true of me**

19 When attending history classes, I would set personal goals for myself in order to direct my own activities during the study period.

1	2	3	4	5
not at all true of me				**very true of me**

20 When studying history, I usually try to explain the textbook chapter to a classmate or a friend.

1	2	3	4	5
not at all true of me				**very true of me**

21 I would try to work with my classmates to complete history assignments.

1	2	3	4	5
not at all true of me				**very true of me**

22 When studying history, I would set aside time to discuss the textbook chapter with my classmates.

1	2	3	4	5
not at all true of me				**very true of me**

23 It is important for me to learn history when playing a game such as “The Jackson Plan”.

1	2	3	4	5
not at all true of me				**very true of me**

24 The most satisfying thing for me in playing “The Jackson Plan” is trying to understand the history links that are presented in the game.

1	2	3	4	5
not at all true of me				**very true of me**

25 I now prefer course materials like "The Jackson Plan" game that arouse my curiosity, even if it can be difficult to learn.

1	2	3	4	5
not at all true of me				**very true of me**

26 Having played "The Jackson Plan", I now prefer course materials that challenge me to learn new things.

1	2	3	4	5
not at all true of me				**very true of me**

27 History is now my favourite subject after playing "The Jackson Plan".

1	2	3	4	5
not at all true of me				**very true of me**

28 How well concentrated were you when you were playing "The Jackson Plan"?

1	2	3	4	5
not at concentrated				**very concentrated**

29 My mind wandered off as I was playing "The Jackson Plan".

1	2	3	4	5
not at all true of me				**very true of me**

30 When playing "The Jackson Plan", I had a sense of "being there" in the game scenes.

1	2	3	4	5
not at all true of me				**very true of me**

31 I felt like I was in a *game world* when I was playing "The Jackson Plan".

1	2	3	4	5
not at all true of me				**very true of me**

32 I felt that the *game world* surrounded me when I was playing "The Jackson Plan".

1	2	3	4	5
not at all true of me				**very true of me**

33 How real did "The Jackson Plan" world seem to you?

1	2	3	4	5
not real at all				**very real**

34 When I was playing “The Jackson Plan”, I was aware of what was going on around me in the real world.

1	2	3	4	5
not at all true of me				**very true of me**

35 In "The Jackson Plan", I could picture myself in the scenes that were described in the game's story.

1	2	3	4	5
not at all true of me				**very true of me**

36 I was mentally focused in the story while playing “The Jackson Plan”.

1	2	3	4	5
not at all true of me				**very true of me**

37 After the game ended, it was easy to put the game out of my mind.

1	2	3	4	5
not at all true of me				**very true of me**

38 The story affected me emotionally (happy, sad, anxious, etc.).

1	2	3	4	5
not at all true of me				**very true of me**

39 I found myself thinking of the other possible endings in the game story.

1	2	3	4	5
not at all true of me				**very true of me**

40 The way in which “The Jackson Plan” was presented is _______________.

1	2	3	4	5
Familiar				**Interesting**
1	2	3	4	5
Unoriginal				**Original**
1	2	3	4	5
Old				**New**
1	2	3	4	5
As expected				**Unexpected**
1	2	3	4	5
Common				**Uncommon**

Appendix E: Learning Achievement Test (Study 2)

1、The island of Singapore was an old fishing village in the early 1800s. After having the subsequent growth of the settlement, it has become a modern and contemporary city. Who founded Singapore?

(A) William Farquhar (B) Stamford Raffles (C) John Crawford

(D) Lieutenant Philip Jackson

( )

2、When was Singapore founded?

(A) On 26 January 1819

(B) On 27 January 1819

(C) On 28 January 1819

(D) On 29 January 1819

( )

3、Which of the following is NOT a reason why Singapore was chosen by the British as a trading station?

(A) It was an excellent harbour

(B) Land was fertile

(C) Availability of good supply of drinking water

(D) Suitability as a port for its central location as a trade route

( )

4、*After a drought wiped out his crops, Mr. Veerasamy Sivalingam, 24, was forced to leave his village near Madras (present-day Chennai) to find a job in the city of Singapore in 1822.* Could you identify which of the following factors made him come to Singapore?: 1) Their countries were suffering from wars; 2) The colonial rule asked them to leave their countries; 3) Better job opportunities; 4) They wanted to escape from poverty in their homelands.

(A) 1 & 2 (B) 1, 2 & 3 (C) 1, 3 & 4 (D) All of the above

( )

5、When the immigrants came, they settled in great numbers near the mouth of Singapore River in a disorganized manner. A British engineer hence drew up a plan in 1822 improve the haphazard settlement. Who was he?

(A) William Farquhar (B) Stamford Raffles (C) John Crawford
(D) Lieutenant Philip Jackson

( )

6、Which one of the following is NOT a key immigrant country to Singapore?

(A) France (B) Malay Archipelago (C) India (D) Egypt

( )

7、In what way was the town plan adopted?

(A) Immigrants were divided according to races and distributed across different areas.

(B) Immigrants were divided according to their trading activities.

(C) Immigrants were divided according to their wealth and social economic status.

(D) Immigrants were divided according to their religions.

( )

8、In the account of the Singapore town plan in 1822, which of the following is FALSE?

(A) Roads of the town were widened, and main streets were lit by feeble coconut-oil lamp. You could take a rickshaw around the town area.

(B) The European and Asian traded side by side at the Commercial Square, you could buy some tea straight from London if you wanted.

(C) The city was well-planned and there was a remarkable absence of tumbled buildings. The swamps and mangroves outside the town area were all replaced by public buildings. People no longer suffered from hunger.

(D) While walking on the streets, you could see Indian labourers constructing roads and buildings.

( )

9、After the founding, traders from all over the world came to Singapore to trade. Which of the following statement of the Entrepot Trade is FALSE?

(A) Agencies repackaged goods from other countries in smaller quantities and exported them to China, Malay Archipelago or India.

(B) Trading was prosperous since traders and ships from all nations could trade freely with one another and they did not have to pay custom duties or tax on goods that they carried to and from the port.

(C) Trade took place easily since the British set up coolie-agency house for new coming immigrants and provided merchants who were looking for workers as much-needed labourers.

(D) Along the river you could see coolies being unloaded off the ships into warehouses.

(　　)

10、As a middleman of the mid-18th century in Singapore, which of the following statements about them is FALSE?

(A) They could speak sufficient English, Malay and local dialects.

(B) The role of middlemen allowed trade to take place easily since they set up shops which provided daily necessities.

That catered to the needs of the locals and created employment.

(C) The role of middlemen contributed to the increase in population since they brought workers into Singapore.

(D) Traders from Europe and Malay Archipelago bought and sold their goods through them, and most of them were straits-born-Chinese.

(　　)

11、An British trader in the mid-18th century who came to Singapore who wanted to trade his imported goods from Europe, which of the following is FALSE?

(A) He could buy products such as rice or tea from China.

(B) He could trade his manufactured goods with Indian merchants for cotton.

(C) He brought in goods in small and delicate quantities for a better price such as wool and cloth

(D) He could look for Malay merchants for exotic spices and coffee.

( )

12a、As a time traveller, you are now back to the mid-19th century in Singapore. You decided to pick up some goods from a British shophouse. Which of the following items might not be from Europe?

(A) A fine green cotton jacket

(B) A hand crafted clock

(C) An elegant, aesthetic designed rifles

(D) A pack of coffee beans with a deep roasted flavor

( )

12b、 After a short walk, you found a shop that supplies precious wood materials for boat repairs. Who might be the shop owner?

(A) An Arab (B) A Chinese (C) A Malay (D) An Indian

( )

12c、You continued walking along the riverside that overlooked daily living activities. Which of the followings is FALSE?

(A) The coolies worked hard with repackaging goods in a warehouse, they are brought here by middlemen.

(B) Many ships from Siam just arrived, carrying rice, sugar and salt.

(C) There were a lot of swaying coconut palms along the riverside.

(D) Many of Indians worked as skilled shipbuilders there, making ships for the Indian traders.

( )

12d、You met a Malay worker at the dockyard where he introduced himself to you. Which account of his life is CORRECT?

(A) When he came here in 1819, the city is well-planned and he found a job in a Chinese shop.

(B) He stayed at a kampung village along the river since there were swamps.

(C) He always wanted to own an exquisite clock from China.

(D) The Malay man said that I could get a job from the British middlemen because they were knowledgeable.

( )

13、When the immigrants came to Singapore, they contributed to Singapore's development and growth. Could you identify the contribution of the <u>Europeans</u>?

(A) A large number of them came here as unskilled labour such as coolies.

(B) Their skilled shipbuilders helped traders to ferry goods to neighbouring islands.

(C) They worked as labourers to carry goods at the docks. They sometimes sold spices on the streets that gave other immigrants a taste of their homeland delicacies.

(D) They owned the shophouses near the commercial square, and they brought in goods in large quantities.

(   )

14、Based on question 13, can you identify which of the following is the contribution of the <u>Chinese</u>?

(A) A large number of them came here as unskilled labour such as coolies.

(B) Their skilled shipbuilders helped traders to ferry goods to neighbouring islands.

(C) They worked as labourers to carry goods at the docks. They sometimes sold spices on the streets that gave other immigrants a taste of their homeland delicacies.

(D) They owned the shophouses near the commercial square, and they brought in goods in large quantities.

(   )

15、Based on question 13, can you identify which one is the contribution of the <u>Indians</u>?

(A) A large number of them came here as unskilled labour such as coolies.

(B) Their skilled shipbuilders help their traders to ferry goods to neighbouring islands.

(C) They worked as labourers to carry goods at the docks. They sometimes sold spices on the streets that gave other immigrants a taste of their homeland delicacies.

(D) They owned the shophouses near the commercial square, and they bought in goods in large quantities.

( )

16、Based on question 13, which of the following is a contribution of the Malays?

(A) A large number of them came here as unskilled labour such as coolies.

(B) Their skilled shipbuilders helped their traders to ferry goods to neighbouring islands.

(C) They worked as labourers carrying cargoes at the docks. They sometimes sold spices on the streets that gave other immigrants a taste of their homeland delicacies.

(D) They owned the shophouses near the commercial square, and they bought in goods in large quantities.

( )

17、Elgin Bridge which today is a vehicular bridge across the Singapore River is believed to have existed as early as 1819. It was the first bridge across the Singapore River. Which two communities did it link during that period?

(A) British merchants and the Chinese community.

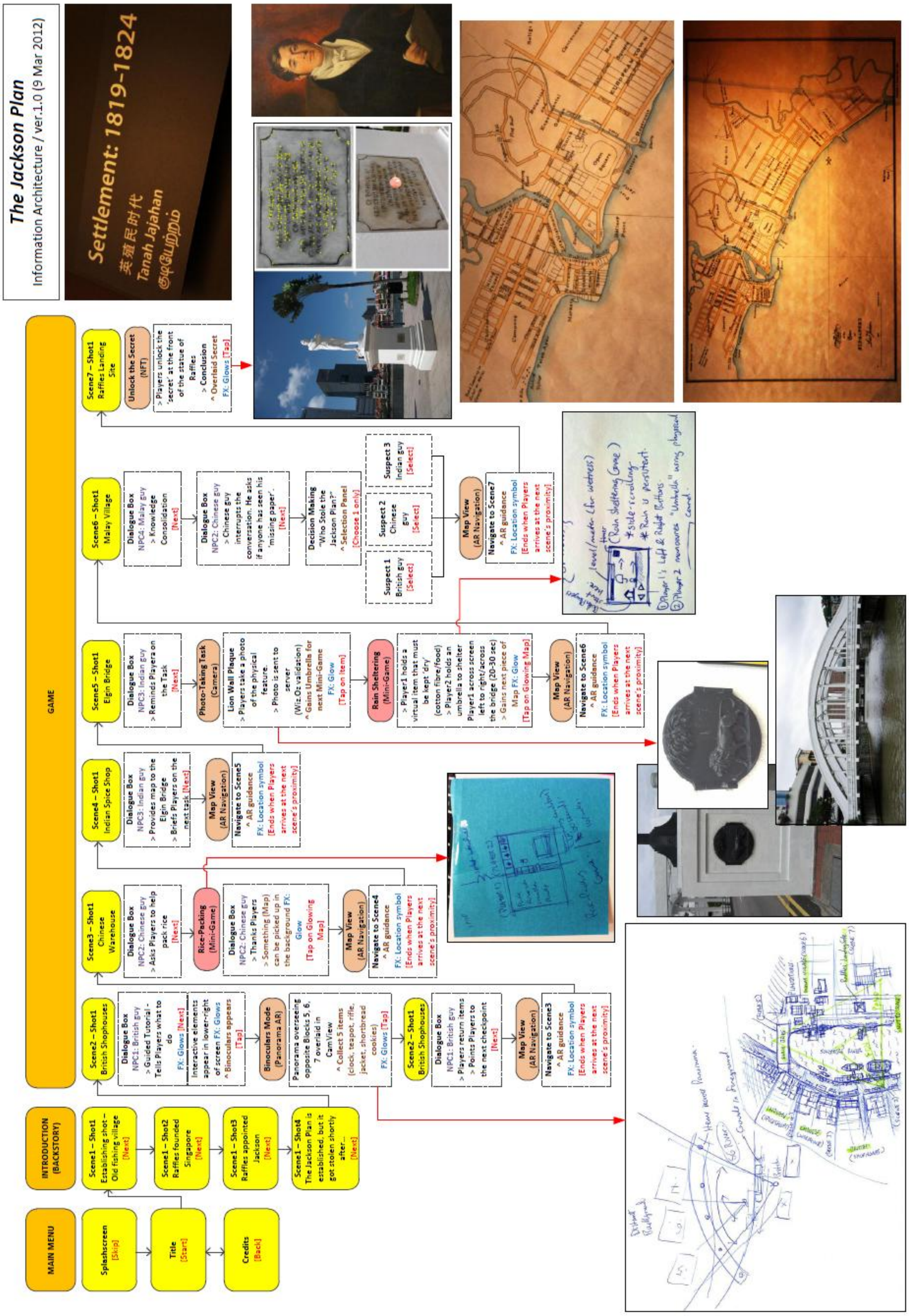
(B) Chinese community and the Indian merchants.

(C) Indian merchants and the British merchants.

(D) Indian merchants and the Malays community.

( )

Appendix F: Interaction flow diagram for "The Jackson Plan" (Study 3)



Appendix G: Newspaper Article

David Ee. (2012, 13 December). iPad game brings history to life. *The Straits Times,* Singapore.

B10 | HOME THURSDAY, DECEMBER 13, 2012 THE STRAITS TIMES

iPad game brings history to life

Students learn by uncovering pieces of 'missing' town plan from colonial era

By DAVID EE

IT IS a history lesson, adventure quest game and field trip all in one. And it has proven to be a hit.

Researchers at the National University of Singapore (NUS) have created an iPad game based on The Jackson Plan of 1822, colonial Singapore's first town plan.

They have managed to bring history to life for students as they walk the Singapore River.

Secondary 1 students at Outram Secondary who tested the game in July not only enjoyed it more than in-class lessons, but they also learnt more and performed better in tests – all with no textbook required.

The game is the work of researchers at the Keio-NUS Connective Ubiquitous Technology for Embodiments (Cute) Centre.

Conceived in December last year, it uses augmented reality and Global Positioning System software to allow students to explore the river and learn facts as they visit historical sites during the course of the game.

Augmented reality allows people to access and interact with virtual content "embedded" in real-world spaces.

Set in 1822, the game casts students as staff of land surveyor Lieutenant Philip Jackson, who drew up the plan. With the town plan having gone missing, they must scour the riverbanks, solve puzzles and speak to in-game characters to uncover fragments of the map.

En route, they pick up historical facts from various characters, including traders, coolies and kampung elders.

The students can unlock game stages by pointing the iPad at designated "game" objects, such as the plaque at the Elgin Bridge and an old postcard of the river.

The game's creators sought to use technology to transform conventional learning habits.

Said Cute Centre co-director Henry Duh: "We are not just promoting this as new technology, we are asking, 'What is the next-generation (method) of learning?' This is how we try to mimic informal learning... to help students learn in interesting ways."

The creators ensured that the game's content mirrored actual textbook content, as well as lesson objectives stipulated by the Ministry of Education.

And students who played the game fared better in formal tests compared to textbook-bound students, by about 15 per cent.

Augmented reality has been used in marketing by fashion giant H&M and in the Guggenheim Museum in New York City. But Dr Duh said that its use in education is still fairly new.

Outram Secondary is in discussions with the Cute Centre to license the game for its use, a spokesman said.

The school intends to go further by "infusing augmented reality" into the school's curriculum.

It is working with the centre to incorporate it into its mathematics lessons too.

The bottom line remains the learning experience, said Dr Duh, adding: "Technology is just a way to reach the goal of learning."

davidee@sph.com.sg

Designer Raymond Koh (left) using a postcard which researcher Deldra Wong's iPad can detect as a "game" object. When the iPad hovers on a Singapore River scene (below), a corresponding scene in old Singapore appears. ST PHOTOS: NURIA LING

NEXT-GEN TOOL

We are not just promoting this as new technology, we are asking, 'What is the next-generation (method) of learning?' This is how we try to mimic informal learning... to help students learn in interesting ways.

– Cute Centre co-director Henry Duh

Appendix H: Publications

This appendix indexes the candidate's respective publications that are cited in this thesis, as well as works that have been published from the research studies conducted during this MA candidature.

1. Works published before the commencement of this M.A. candidature (10th January 2011) that are **not** part of the core contribution of this thesis,

1. **Koh, R.K.C.**, Duh, H.B.-L. and Gu, J. (2010). *An integrated design flow in user interface and interaction for enhancing mobile AR gaming experiences*. Paper presented at the 9th IEEE International Symposium on Mixed and Augmented Reality - Arts, Media, and Humanities (ISMAR-AMH), Seoul, Korea, 13-16 Oct. IEEE. DOI: 10.1109/ISMAR-AMH.2010.5643296

2. Gu, Y.X., Chen, V.H.-H., **Koh, R.K.C.** & Duh, H.B.L. (2010). *Facilitating Learning Interests through Mobile Information Visualization.* Paper presented at the 10th IEEE International Conference on Advanced Learning Technologies (ICALT), Sousse, Tunisia, 5-7 July. IEEE. DOI: 10.1109/ICALT.2010.92

3. Duh, H.B.-L., Chen, C.-H., Su, C.C.-C. & **Koh, R**. (2009). *An intuitional interface for invocation of Chinese painting.* In: Proceedings of the 8th IEEE International Symposium on Mixed and Augmented Reality - Arts, Media and Humanities (ISMAR-AMH), Orlando, Florida, 19-22 Oct. IEEE. DOI: 10.1109/ISMAR-AMH.2009.5336722

2. During this M.A. candidature the candidate has published and presented 4 research papers in peer-reviewed international venues.

1. **Koh, R.K.C.**, Duh, H.B.-L., Chen, C.-H., & Wong, Y.-T. (2012) *Co-Creativity Fusions in Interdisciplinary Augmented Reality Game Developments.* Paper presented at the 11th IEEE International Symposium on Mixed and Augmented Reality - Arts, Media, and Humanities (ISMAR-AMH), Atlanta, Georgia, 5-8 Nov. IEEE.

2. **Koh, R.K.C.**, Duh, H.B.-L., Chen, C.-H., & Wong, Y.-T. (2012). *Playing Together: Supporting Children-Played Outdoor Location-based Handheld Augmented Reality Game Deployments*. Paper presented at the 2nd Workshop in Mobile Augmented Reality: Design

Issues and Opportunities, 14th ACM SIGCHI International Conference on Human-Computer Interaction with Mobile Devices and Services (MobileHCI). San Francisco, California, 21-24 Sept. New York: ACM. DOI: 10.1145/2371664.2371720

3. Chang, Y.-N., **Koh, R.K.C.,** & Duh, H. B.-L. (2011). *Handheld AR games - A triarchic conceptual design framework*. Paper presented at the Mixed and Augmented Reality - Arts, Media, and Humanities (ISMAR-AMH), IEEE International Symposium On, Basel, Switzerland, 26-29 Oct. DOI: 10.1109/ISMAR-AMH.2011.6093653

4. Chang, Y.-N., **Koh, R.K.C.,** & Duh, H.B.-L. (2011). *A triarchic conceptual framework in handheld augmented reality games.* In: M. de Sá, E. F. Churchill, & K. Isbister (eds), 1st Workshop in Mobile Augmented Reality: Design Issues and Opportunities, 13th ACM SIGCHI International Conference on Human-Computer Interaction with Mobile Devices and Services (MobileHCI). Stockholm, Sweden, 30 Aug - 2 Sept. New York: ACM. DOI: 10.1145/2037373.2037504

** Papers published under this research are attached herein after this page.*

Co-Creativity Fusions in Interdisciplinary Augmented Reality Game Developments

Raymond Koon Chuan Koh[#a]
Keio-NUS CUTE Center / IDMI / ECE
National University of Singapore

Henry Been-Lirn Duh[b]
Keio-NUS CUTE Center / IDMI / ECE
National University of Singapore

Cheng-Ho Chen[c]
Keio-NUS CUTE Center / IDMI
National University of Singapore

Yun-Ting Wong[d]
Keio-NUS CUTE Center / IDMI
National University of Singapore

ABSTRACT

This paper recognizes and reflects upon the important co-creativity roles and intimacies that arts students may play in increasingly interdisciplinary environments where research and design potentials of evolving new media technologies are being explored. We report a real-world case study where two students played the dedicated artists' roles of art and game design developments while working with staff researchers from technical, design and social science (education) backgrounds to develop an outdoor location-based handheld augmented reality game project. The paper relates how a clearer understanding of such didactic situations can empower and invoke co-evolutions of both art and technology.

KEYWORDS: Interdisciplinary Research, Augmented Reality, Human-Computer Interaction, Games.

INDEX TERMS: D.2.10 [Software]: Design — Methodologies; H.5.1. [INFORMATION INTERFACES AND PRESENTATION]: Multimedia Information Systems – Artificial, augmented, and virtual realities; K.8.0 [PERSONAL COMPUTING]: General – Games

1 INTRODUCTION

1.1 Practitioners and Students of Creative Arts in Interdisciplinary New Media Research

1.1.1 The Practice

There is a fundamental difference in the creation of art for 'new media' as compared to older or traditional forms of (visual) art as it requires a collaborative infrastructure to produce and regularly involves (in academia) a network of artists, technologies, research collaborators, funding institutions, curators and exhibiting venues/structures [1]. [2] termed this as 'software-dependent artwork' which interdisciplinary projects offer as co-creation opportunities for software developers and artists to work closely together. The notion of artists and technologists working together is however not new ([2-4]) even in the Augmented Reality (AR) technology space ([5]) and empirical models to scientifically exemplify the co-creativity processes that exist between such relationships have been previously proposed (i.e. [6] for mixed media, and [7] for interactive art). Technology researchers when working with collaborating artists tend to attribute that artists would consider their (artists') own participation to be a form of *practice-based research* ([8,4]), one that is often heavily influenced by Schön's *'reflective'* concept of the self ([9]), according to [3]. Artists on the other hand, when seeing technology as an artistic medium, draw creative ideas by using an in-depth knowledge of how technologies operate through experimentations [5].

1.1.2 Maintaining an Equilibrium

Apart from the promised synergies of innovations that such interplaying arrangements are said to bring, 'sparks' (friction) may also occur in artist-technologist collaborations ([10]) and not function smoothly due to one or many of the following reasons - 1) *diverse disciplines of participating collaborators*, 2) *inexplicit system specifications in artwork requirements that are subject to changes even during late stages of a project*, and 3) *collaborations between artists and technologists are often driven by creativity and innovation rather than by a specific functional purpose* [2], etc. In a review of practice-led research, [8] identified that possible barriers of languages may exist between academics and practitioners. A bottom line thus lies in the relationships between individuals, ideas, actions and productions as *communication* (bearing a feedback-loop structure of continuous 'form and re-form' [11]), and *mediation* ([10]) processes of individual participants during an actual collaboration that is assimilated over various periods of time and within diverse socio-political situations [11,6].

In the view that theory and practice can each lead to developments of the other ([7]), a collaboration process that forces us to reposition our thinking can lead to new insights (creative and novel uses) for arts in the technology space [4], produce positive outcomes of integrated cross-disciplined knowledge [3], and identifies requirements for support environments [11,6]. It is held in the common belief by the stakeholders involved (collaborators from different backgrounds) that **access**, **knowledge** and **understanding** of the capacities of the technology and its associated constraints (direct and indirect implications) will allow the creative exploitations of technology in envisioned novel applications and approaches ([12]), the development of new aesthetics ([5]) and conventions ([13-15]) beyond traditional forms [5]. Both [12] and [13] are *ISMAR-AMH* papers (2010 and 2011 respectively) of this paper's *first 2 authors* that have specifically fronted the understanding of technological limitations to be a design requirement when envisioning designs for handheld AR (HAR) gaming experiences.

1.1.3 Creative Apprenticeships

The involvement of practitioners and students of creative arts through varying degrees, purposes and goals in technology-oriented initiatives can be seen or described as related work in the following literature – *using evolving AR technology (fiducial*

[#] Division of Industrial Design, NUS
{[a] raymondkoh, [c] idmcch, [d] deidrawong}@nus.edu.sg [b] duhbl@acm.org

IEEE International Symposium on Mixed and Augmented Reality 2012
Arts, Media, and Humanities Proceedings
5 - 8 November 2012, Atlanta, Georgia
978-1-4673-4664-1/12/$31.00 ©2012 IEEE

markers) as an artistic and aesthetic medium of self-expression [5], *building an AR-painting interface to support a specific art style* [16], *teaching design through the development of an AR game* [17], *practical production management skill training* [11], and *structuring higher education (PhDs)* [8], etc. Practical training from real-world projects has been increasingly included in academic curriculum (Section 2.1 in our case and in [8]). In an *artist-student* collaboration (where an arts practitioner works with a technical developer-student), the biggest risk in having student effort apart from professional efficiency and inexperience is not knowing if the project would deliver a working system or not, resulting in an entrenching sense of insecurity [2]. We liken to think the same of the exact opposite collaboration style – a *technologist-student* arrangement where end outcomes as creative design executions of technology(ies) bears the same perceived risk and consequence of being unworkable and thus produce the very same negative disposition of uncertainty. To this end, we would like to highlight that *game design* ([18]) is seen as a specialization in the field of creative arts in this writing, and so the assertions and descriptions that have been detailed so far about artist-technologist collaborations are said to be also applicable to the discipline as well.

1.2 Interplaying Relationships

Research is an inquest into knowledge creation along a journey of learning. Mason believes that the "discipline of noticing" is crucial to the work of researching one's own practice [24]. This paper reflects on the practice-led generative design ([17]) transpirations of a work arrangement with two creative arts students, both as 'full' practitioners in 2-D art and game design developments respectively. The students worked in an interdisciplinary collaborative environment with three researchers from technical (technology), design and social science (education) backgrounds. The aim was to co-develop an outdoor educational location-based game during the students' 6-week ITP (Section 2). Using the resultant design outcomes of the two student-artists, in particular the structured mini-games' ([19]), we inform interaction design by proposing a *single display groupware* ([21]) interface for supporting a dual-player outdoor co-located ([22,23]) HAR gaming experience. We prime our case as a successful development with student-artists that may be useful to inspire future work with such an interdisciplinary design approach.

2 BACKGROUND OF THE CASE STUDY

2.1 The Initiative

The Keio-NUS CUTE Center in the National University of Singapore[1] has been hosting student interns from the School of Design's **Games Design and Development** program in **Singapore Polytechnic** (SP)[2] under their 6-week **Industrial Training Programme (ITP)** since 2009. This is also commonly known as an 'internship' in some countries where students are attached to an external organization to gain practical work experience that is relevant to their field of study. For ITP, students receive a fixed stipend to cover basic subsistence costs. A weekly overall progress report is sent to the *Principal Investigator*. In past batches, each student of game design and/or digital art (2-D or 3-D) specialization(s) (varied according to our specific skill set request to the school) was assigned to at least one graduate staff researcher of humanities (social science or design) background, and one other graduate staff researcher of either computer science or engineering background, and worked in interdisciplinary Games-, Education-, Mobile- and/or AR-related projects, i.e. Artwork for the prototype in [12], our ISMAR-AMH (2010) paper was previously co-created by a student-artist under SP's ITP.

Figure 1. Artifacts photographed at National Museum of Singapore, (Left): Portrait of *Sir Stamford Thomas Bingley Raffles.* (Middle, Right): "Jackson Plan" (1822) / Close-up.

2.2 "The Jackson Plan"

2.2.1 Motivation

"The Jackson Plan", also known as the "Plan of the Town of Singapore" is an actual urban town plan drawn up *by Lieutenant Philip Jackson*, an engineer and land surveyor of the British colony, in the **year 1822** to manage the early multi-racial (predominantly the Chinese, Malays, Indians and British) immigrant settlements (Figure 1, Middle & Right), and is named after the same. It is featured as a specific chapter of the history subject for lower secondary students in Singapore public schools that is, *Sir Stamford Thomas Bingley Raffles'* (Figure 1, Left) founding of modern Singapore in the **year 1819** as an important trading seaport ([25]). Several important geographical sites for key historical events and trade activities conducted by the then-populations that followed with the founding are today historical landmarks along *Singapore River* (Figure 12). The learning experience of this history chapter would be made as a *short and light* **location-based game** (LBG) experience with HAR features for selected *contextually-relevant* ([26]) places.

2.2.2 Initial Educational Design Themes

Domain knowledge of the learning content (Table 1, Column 1) was first drawn by the educational researcher from the academic syllabus[3] and translated into design themes (Table 1, Column 2).

2.2.3 LBG Specifications

The game is to be played by a pair of students and each game session would be accompanied by an adult moderator for facilitation ([27]) and safety reasons ([28]). Considering potential straying player-movements during actual game runs with children, we decided to feature a single-display groupware ([21]) play mode using one handheld device (Apple iPad 3rd Generation), thus physically co-locating both players in closer proximity to the moderator. The single-display groupware presentation ([21]) is intended to help retain children's attention, while facilitating discussions and collaborations between the player-pair ([21,23]), noting however that learning effects of the game prototype are not within the scope of this paper.

Well-designed placements of information in virtual or AR systems where communicative intent is specified by a prioritized list of communicative goals make it possible for the experience of a world that does not exist or one that exists at another time or place [29]. Initial gaming concepts are drawn from [30,31], and from the following location-based work for features – the use of a narrative and HAR effects (*geo-registered panorama artwork, photo-taking activity, physical feature recognition through image-*

[1] http://cutecenter.nus.edu.sg/

[2] http://www.sp.edu.sg/

[3] http://www.moe.gov.sg/education/syllabuses/humanities/files/history-lower-secondary-2006.pdf

based AR) to bridge historical contexts to evocative places [32], linearity in narrative design [33], and the use of an adventure game structure [34,35]. To enrich the user experience, 'mini-games' ([19]) are used as game activity segments at selected prominent locations to feature novel interaction(s) (i.e. [36]). Mini-games are short simple games that focus the player's attention on a particular item or event during an exploration process of a bigger virtual game world. The activities may bear well-known game models/genres ([34]) but should be immediately playable so that player can focus on the content rather than on learning how to play ([19]). The end deliverable expected of this co-creativity execution was a functional game prototype.

Figure 2. Direct isomorphic-mapping of game to real-world space.

2.2.4 Defining Real-World Game Space

As the "Jackson Plan" is an actual architectural drawing (Figure 1, Middle/Right) it served as a spatial reference to the game space (the direct isomorphic method [37] was applied in our case), albeit only relatively on the corresponding physical real-world area because of architectural changes over the last two centuries (Figure 2). This mapping process influenced game design (game event placements in Section 3.2.1) as in Figure 3. A quick *bodystorming* ([38]) was conducted at the proposed game site by the researchers to confirm that the selected HAR-technology deployment spots were usable. The associated limitations surrounding the technological features in Section 2.2.3 were determined or at least identified during the session, i.e. image-based AR recognition/ location tracking stabilities were tested at different times of the day. This technique has been found to be useful for *physical site-sensing* [39], and for *LBG ideations* [17]. During the initial conceptualization of the project, there were concerns with the available options for physical AR-feature recognitions (considering sunny outdoor lighting conditions), and with possible GPS inaccuracy issues (as the area is along a river with skyscrapers nearby).

3 METHODS

Sections 2.2.2, 2.2.3 and **2.2.4** were completed ahead as a pre-study by our host group that comprised of three researchers from *technical-technology (rT)*, *design (rD)* and *social science-education (rE)* backgrounds respectively as soon as it was confirmed that two SP students would be working with us in dedicated artist roles (2-D art and game design) as their ITP (Section 2.1), noting however that only one student (the one on 2-D art) was originally assigned to work on "The Jackson Plan". We had intended for this student-artist to take on part of the game design tasks, given that students undergo the same foundation courses in SP. *rD* was the students' supervisor for this ITP, and the project's producer. Both *rD* and *rT* have prior professional experiences in the creative industries. We have excluded the *Principal Investigator* from the host group in **Methods** because we are focusing on the daily interactions and exchanges that the researcher group had with the SP students during the ITP interim. The remaining parts of this section are – the *knowledge empowerment process* (Section 3.1), *what we did as a group* (Section 3.2), *the co-assignment* (Section 3.3), *individual and sub-group contributions of group members* (Section 3.4), and *iterations* (Section 3.5). Preproduction and production documentations, design notes, logs, and e-mail/oral communication transcripts are used to present this case study.

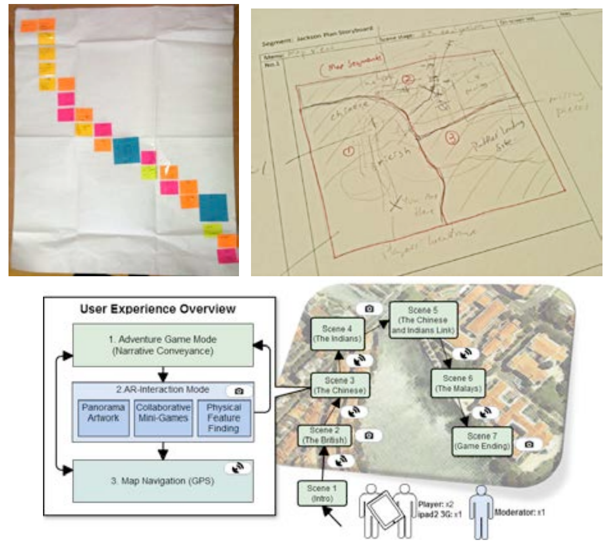


Figure 3. (Top-Left): Game structure for "The Jackson Plan", (Top-Right): Game area / map segmentation discussions, (Bottom): User experience overview.

3.1 Knowledge Empowerment and Access

During the first week we introduced AR technology overviews to both *Student-Artist A (SA)* the 2-D Artist, and *Student-Artist B (SB)* the Game Designer. Both of them had no prior working/industry experience. Although *SB* was initially assigned to another less work-intensive project that was led by another researcher colleague (not in "The Jackson Plan" group), we felt that the lecture might be interesting to him and hence included him in the remaining group ideation activities of this section and Section 3.2.We will however explain later how *SB* was eventually involved with mini-game design work for our project. The following topics were covered using still images, videos and selected research papers during the introduction - 'History of Mobile AR'[4] [40], features that can be used in HAR game design [13][41], common HAR challenges (from our pre-study and [42]), and we provided examples using 'Spirit Camera'[5] and *Games Alfresco's* list of AR games[6]. Technological constraints that we knew of were highlighted along the way. We also allowed the students (where possible) to have 'hands-on' physical plays with HAR software-loaded devices (Apple *iPad 3rd Gen.* and *iPhone4S*) that were accessible during working hours. This turned out to be their first exposure to AR (actual interactions with the technology). Next, we introduced "The Jackson Plan" (Section 2.2.1) using the history textbook ([25]), initial design themes (Section 2.2.2), and images taken during the bodystorming session

[4]https://www.icg.tugraz.at/~daniel/HistoryOfMobileAR/

[5]http://spiritcamera.nintendo.com/

[6]http://gamesalfresco.com/2009/06/27/your-favorite-augmented-reality-games-of-all-time/

(Section 2.2.3). We encouraged the students to talk to the team members on any respective domain subject at anytime.

3.2 Co-Creation Activities (Whole Group)

3.2.1 Narrative and Game Concept Abstractions

A 'Post-Its' session led by *rD* was used to discuss and ideate the **game structure** of the adventure-styled LBG by the group, colored squares represented different game event segments, i.e. scene chapter points including transitions between geo-specific panorama artwork and HAR feature modes (orange), within-scene screen transition points (yellow), dialogues for *Non-Playable Characters/NPCs* (pink), and requirements for mini-games with HAR features (blue), as in (Figure 3, Top-Left). Player-actions and interactions for triggering in-game transitions were discussed and denoted on the individual Post-Its, forming the **narrative's overall flow** in (Table 1, Column 3) that was used in Section 3.4.2.

Table 1. Translations of learning concepts to design elements

Individual Developments (*rE*)		Co-Creations (Whole Group)	
Column 1	Column 2	Column 3	Column 4
Learning Concept	Design Themes	Narrative Development	Activity Design
1. Background of Singapore Settlement	* Small fishing villages * Trading activities at dockyards * Mixed populations (multi-racialism) *British-shops	Players are assigned to locate the missing "Jackson Plan". They are also asked to talk to several people (NPCs) to gather background information.	Players are to pick up virtual items in a geo-referenced panorama artwork of the past.
2. Entrepot Trade	*Daily lives of coolies/workers (multi-racialism) *Middlemen's trade role *Food depot (i.e. rice and tea) *Chinese factories	Players learn the primary trade activities of the population group (importing and exporting of goods) by talking to the Chinese middleman (NPC) in the rice factory.	Players experience the 2-player "*Rice-Packing*" mini-game that requires teamwork using the same device.
3. Contributions of Immigrants	* Emphasis on cotton trade * 'Elgin Bridge'- A monumental bridge that once served as a trading link *Dockyards	Interacts with a virtual Indian coolie (NPC) who explains his job and livelihood to Players. He provides navigational information to the next point of the game.	Players are required to take the photograph of the correct prominent physical feature situated along the predesignated route. They play the "*Rain-Sheltering*" mini-game of synchronized movements.
4. Comparisons of Immigrants' contributions	* A Malay village along the river * Supplies and service provisions (i.e. Malays shipbuilders) * Raffles Landing Site / 'The Statue of Raffles'	A Malay elder (NPC) acts as a facilitator who helps Players to organize and reflect on the overall information fragments from the gaming experiences (who have they met and their respective contributions to the settlement).	Players unlock a secret virtual document through *markerless-* AR recognition of a physical feature at this location (The 'Statue of Raffles' at the Raffles Landing Site).

The game features an in-game map that scaffolds and reveals new destinations as extended map pieces with game progress (Figure 4). This is used in conjunction with GPS navigation to guide players to the predesignated locations that are to be visited, as players would learn during the game. As such, the game area was divided into three segments (Figure 3, Top-Right) in preparation for its art development (Section 3.4.3). A total of **7 scene events** excluding the game's opening title were created from the game structure (Figure 3, Top-Left) and sequentially distributed across the layout of the **game area** from Section 2.2.4 in the order of historic relevance to establish the **user experience overview** as in (Figure 3, Bottom). The resultant outputs of this section allowed the team to have the necessary base references to respectively work on from thereon, either individually or in sub-groups (Section 3.4). We also compiled a report for a content review by an external education researcher with teaching experiences. A master schedule that was negotiated between the group's researchers was drafted at the beginning of **Week 2** based on the outstanding required tasks for the project – a detailed narrative script (mainly developed by *rE* and edited by *rD*, Section 3.4.1), game designs for the mini-games (by *SA*, Section 3.4.2), art assets to be produced (by *SA*, Section 3.4.3), preparations of information architecture, key concept sketches and overall coordination (by *rD*, Section 3.4.4), and system development (by *rT*, Section 3.4.5). *SB* had not been assigned any individual work tasks at this point as he was left to work on the project under the original assignment.

Figure 4. Segmented in-game map (3 pieces).

3.3 The Co-Assignment

Towards the end of **Week 2**, the researcher team co-assigned *SB* (who was at that time working on another project) to the designing of the mini-games in order to keep up with the schedule. Progress had been pressured mainly by the extra time that the team took with *SA* to determine the visual style and detail that could be achieved in the given time for the art assets (the whole process took longer than anticipated).

3.4 Individual/Sub-Group Contributions

We describe the work that was completed by individual team members or sub-groups in this section.

3.4.1 Narrative Refinement (Script)

The final narrative script was prepared by *rE* using (Table 1), and edited by *rD* for context continuity in the game design.

3.4.2 Mini-Games' Developments

As a result of the co-assignment (Section 3.3), *SB* worked on initial conceptualizations for the two mini-games' designs from the discussions of (Section 3.2.1). His specific directions from *rD* were that although not a requirement, mini-games should preferably include HAR features/interactions. *SB* later directly worked with *SA* to assess the design requirements for the mini-games' art assets (2-D graphics).

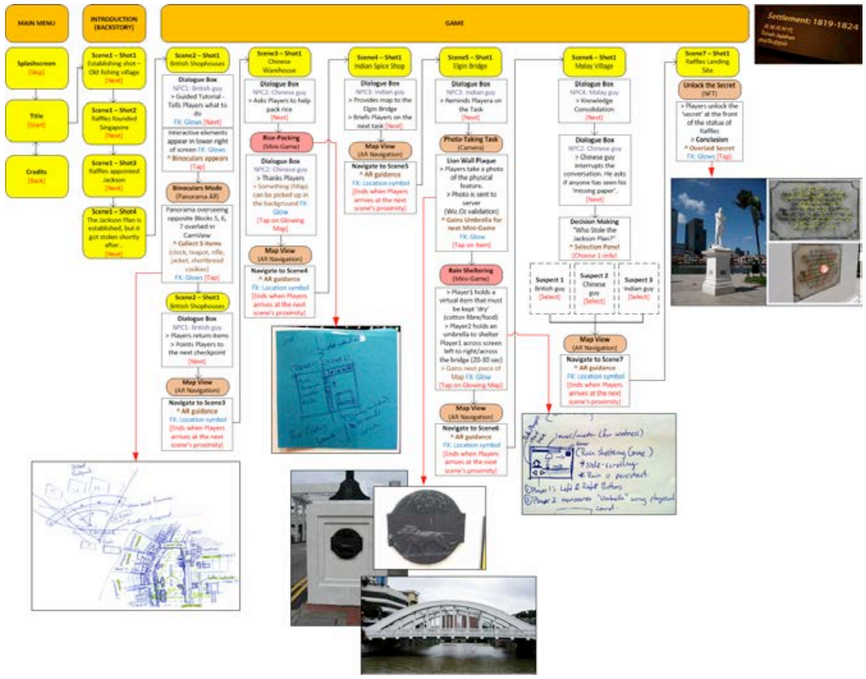


Figure 5. Interaction flow for “The Jackson Plan”.

3.4.3 2-D Art Development

The required artwork to be completed by *SA* comprised of the following – artwork for 7 game characters (2 poses each), 12 scene backgrounds, 17 mini-games’ UI elements, 5 objects and 1 background for the panorama artwork (using Figure 6 to ‘project’ the required perspective), 1 in-game map (Figure 4), and 1 splash-screen (main title page for the game). Historical visual references were compiled by *rD* and *rE* from various public sources, including the National Archives of Singapore[7].

3.4.4 Interaction Flow and Coordination

rD prepared an interaction flow diagram (Figure 5) and a conceptual visualization overview (Figure 6) from the group’s discussions (Section 3.2) that guided requirements for the mini-games’ developments (Section 3.4.2) and the panorama artwork (Section 3.4.3). Figure 5 also charted the information flow in preparation for system development (Section 3.4.5).

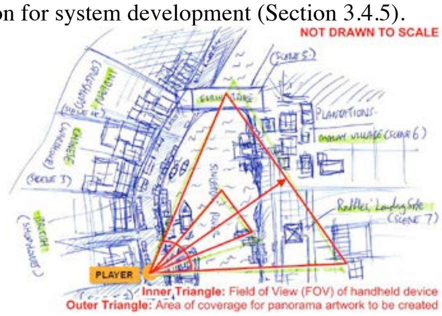


Figure 6. Conceptual visualization overview.

3.4.5 System Development

rT developed the system for the LBG based on the discussed requirements in Section 3.4.4 (Figure 5). The selected platform for “The Jackson Plan” was the *Apple iPad (3rd Generation)* in consideration of the following features – *has a relatively large screen, GPS, gyroscope, camera, and sufficient rendering power for vision-based markerless*-AR *experiences*. *Cocos2d*[8] was used during development to structure the multi-functional system architecture of the adventure game that included character dialogues, game scenes, screen options, and in-game mode switches of the LBG. When it became evident that visual HAR features would be used as designed activities (through Section 3.4.2), Qualcomm’s *Vuforia*[9] was included to embed *markerless*-AR support. As *SB* was keen to be involved with system development work, he helped out in *LUA*[10] scripting tasks for the game scenes (sequencing events and character dialogues).

3.5 Iterations

Group meetings although regular (up to twice a week), were usually impromptu due to evolving project needs. During the 6 weeks that passed, there were several instances of interdependencies in the packed activities of Sections 3.2, 3.3 and 3.4 that demanded immediate iterative cycles of feedback and revisions on issues and ideas that surfaced, i.e. we discussed *SA*’s artwork and *SB’s* mini-game ideas (Section 3.4.2) to combine narrative and collaborative elements into them (Table 1, Column 4), which were then used to refine the narratives (Section 3.4.1).

4 RESULTS

In this section, we focus to report on the outcomes of *SA* and *SB* for the respective tasks of art development and game-design work.

4.1 First Design Iteration (Concepts)

4.1.1 Art development (Initial Sketches)

Conceptual sketches were initially proposed by *SA* (Figure 7), which required the approval of *rD* (first on the visual element

[7] http://www.nhb.gov.sg/nas/

[8] http://www.cocos2d-iphone.org/

[9] https://developer.qualcomm.com/develop/mobile-technologies /augmented-reality/

[10] http://www.lua.org/

selections and compositions, and later on colors and shading, etc.). *rE* advised on the possible inclusions of appropriate educational themes into the artwork (i.e., Table 1, Column 2). Several of the early conceptual sketches were reworked numerous times in **Week 2**, causing the team's overall progress to fall back slightly. By **Week 3** (which was halfway into the 6-week ITP), *rD* asked *SA* to instead prepare a self-projected task schedule while factoring the remaining work balance and the number of working days left (which was actually only 17 days).

Figure 7. Artwork by *SA* - Line sketches and colored backgrounds.

4.1.2 Ideas for Mini-Games

SB produced 10 mini-game ideas in two days. A few of these ideas had screenshots of existing games to illustrate specific game mechanics or HAR features. The researcher group selected the following two initial ideas to develop further from (Section 3.5),

- **Mini-Game 1**: The Player plays a Siamese worker to put the sacks of rice on the shelves of the storeroom by dragging and dropping the rice sacks.
  - *Scoring is based on time.*
  - *The other player can perhaps control a piece of cloth using an AR marker to wipe off the kerosene before the first player is able to place a rice sack on the shelf.*
- **Mini-Game 2** (Figure 8): Player assumes the role of a worker who has to build a bridge to cross the Singapore River. There are bricks and support pillars that can be used to construct a bridge. The bridge would not hold together if there are no support pillars. The bricks would not hold if no cement is applied.
  - *The first player is only able to move left and right to pick up objects to construct the bridge.*
  - *Players can only complete the mini-game if they get to the other end of the bridge. There is no scoring system.*
  - *Using an AR marker, the second player is able to determine the positioning of the objects. It has to be close to the first character in the game. A button is used to confirm the positioning of the object.*
  - *If Players try to walk across without completing the bridge, they would fall into the river and respawn at the starting point.*

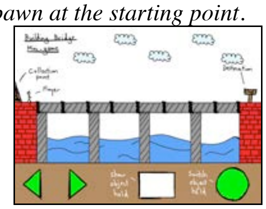


Figure 8. *SB*'s initial concept for Mini-Game 2.

4.2 Second Design Iteration (Low Fidelity Prototype)

Both the mini-games were revised further (described in the next paragraph) by the researcher team to structure player-collaborations through synchronous game activities with embedded contextual information from Table 1. Given the target user audience (secondary school students) and the intended use site (urban outdoors), we wanted an easy and uncomplicated interaction design for these mini-games (i.e. Rules must be simple and intuitive enough such that it would be possible for players to win at the first try). The use of physical AR card markers (i.e. Figure 13) was included to enrich player-interactions and player-scorings were combined from both mini-games.

- **Modified Mini-Game 1 ("Rice-Packing"):** In *SB*'s initial revision (Figure 10, Left) the physical-card holding player's position was on the right side, which we swapped because of the intended orientation of the in-built camera of the handheld device (top left corner from a user's left hand when the device is held up, i.e. as in Figure 11). We also reduced the physical card-orientation options from three to two as we found during playtesting that a complete 180-degree card-rotation gesture was unpleasant and unintuitive to physically perform repeatedly without obstructing the camera's view. Players collaboratively pack sacks of rice in corresponding sequential steps for 'packing' (Player 1, using on-screen UI to perform sequentially-ordered moves) and 'catching' (Player 2, using physical card marker orientations to trigger appropriate 'basket' changing and catch falling colored-sacks in time). Only complete cycles of the two players' actions count towards scoring. 'Mis-packed sacks' (those that have been packed using broken sacks) are to be thrown into the virtual trashcan.
- **Modified Mini-Game 2 ("Rain-Sheltering"):** (Figure 10, Right) shows *SB*'s initial revised concept that depicts synchronous player-movements (numbered 1 to 2 in the green and blue circles) and random obstacles (winds, twigs/stones, and rain as numbered in the black circles 3 to 5) hinder players' movement efforts. The meter-bar (black circle 6) indicates the dampness of the cotton (having been exposed to rain). Player 2 (using a physical AR card marker to control a virtual umbrella) shelters Player 1 (using on-screen buttons to maneuver a virtual cart of cotton stock) to keep the cotton dry while crossing the obstacle-filled bridge.

An offline low fidelity prototype was created in **Week 4** with the inputs of *SA's* artworks (temporary proxies were used for on-going/incomplete parts), and *SB's* reworked mini-game ideas into the system by *rT* that allowed for the independent play-testing of the two mini-games and the panorama art feature by our group members and other colleagues in the lab (Figure 9). Playtesting and preliminary feedback from testers allowed *SB* to propose how the mini-games' interactions should be tweaked and balanced (in discussions with *rD* and *rT*) as the mini-games were initially left in an 'unconstrained' state to explore limitations and extents. Art development by *SA* continued (Figure 11, Bottom).

Figure 9. Low fidelity prototype (left to right): Mini-Game 1, Mini-Game 2, and Panorama Artwork Feature.

4.3 Third Design Iteration (Refined Prototype)

In line with his own schedule, *SA* spent the last few days of the remaining ITP period on artwork refinements. *SB* by this time had completed his tasks for "The Jackson Plan", and was working on another project. For the remaining game balancing tasks, interactions for the two mini-games' were fine-tuned and mapped to constrain parameters by *rT*. In Mini-Game 2 for example, detected physical AR card movements for Player 1's virtual umbrella movements have been constrained to the horizontal axis, i.e. vertical card translations are ignored. Through playtesting of the low fidelity prototype, we found that this constrain eased the control of an on-screen virtual element using a physical gesture. Geo-location service was linked up with game events to complete the prototype (Figure 11). The researcher group only managed to conduct a field trial with the refined prototype after the ITP.

Figure 10. *SB*'s revised concepts: (Left) Mini-Game 1, (Right) Mini-Game 2.

5 Reflections

The outcomes of practice-led research can be valuable to others who are pursuing the same track [7]. We have presented in detail our experiences (processes, issues, and outcomes) of working with student-artists to develop a LBG game using AR as an evolving technology ([14,44]). While it is easy to differentiate the contributions of artists in conventional practices of arts (i.e., contemporary, fine, or digital, etc.), technologists have long debated whether their own form of creation is purely technical or whether it can be viewed as an art when an *'initial creative spark is fanned into a flame'* [4]. We think that the same debate is valid when creative artists start to pick up technologies to directly work with, as [5] or *SB* (in a way) did.

5.1 Relational Reciprocities

We have shared a real project development that was filled with industry-like requirements, and generatively worked with the two student-artists for most parts as equal stakeholders. Their inputs and opinions became integral parts of the project's designs. On the last day of the ITP, the students were asked for their opinions of their ITP work experiences. *SA* replied, *"It was very tiring"*, and *SB* responded, *"It was fun and interesting"*. We attempt to review these statements and relate possible causes for them.

Despite being able to complete the planned project in the relatively short span of 6 weeks, several compromises were made. Our schedule for the required artwork was reworked on as visual quality (a highly subjective attribute) had to be balanced with realistic time allocations. *SB*'s co-assignment (Section 3.3) was actually due to his confession to *rD* that he did not enjoy game-design, to the extent that he appeared stressed over this initial task allocation (observed by *rD*). The schedule that *SA* prepared later seemingly instilled a sense of self-awareness of his own pacing in relation to how others worked, and he did pick up momentum about a week later. It is apparent that *SB* enjoyed his work very much, as he shared ideas and concepts that blended freshly gained knowledge (technological features and/or limitations). Despite also being in a work environment for the first time, he had a curiosity into (HAR) technology that researchers constantly fed into (knowledge empowerment, [5]).

Figure 11. (Top) "The Jackson Plan", (Bottom): 180º geo-registered panorama artwork feature.

5.2 Post-ITP In-depth Interviews with Student-Artists

The researchers conducted a 50-minute in-depth interview with each of the two student-artists to follow up with their views on their ITP experiences in order to answer the following questions - *Q1) What issue(s) did the team face during the project? Q2) Did our knowledge empowerment methods enable the co-creativity processes that had led to the final outcomes? Q3) Did the student-artists feel that a collaboration process had occurred between the researchers and them?* In order to elicit appropriate responses from the subjects to help answer these questions, key guiding questions from (Table 2) were used to direct the interviews. We then transcribed their responses from the digital audio recordings.

Table 2. Guiding questions for in-depth interviews

For Q#	Guiding Question (GQ)
1	Which aspects of the ITP did you like or dislike? (i.e. daily routines, task allocation, schedules)
2	Describe how you learned about AR. Which approach do you think had been the most effective/important for you to learn about AR?
2, 3	Describe your main role(s) and tasks in 'The Jackson Plan'
1, 3	What challenges did you face when working with the team members?
1, 2	What difficulty(ies) did the team face during the project? How do you think this was eventually resolved?
2, 3	Do you think that we had omitted something (during the ITP) that might have helped you learn even more (on AR learning)?

Summary of responses for Student-Artist A

Q1. *SA* listed 'communications' as a problem for him and the team. He found it difficult to understand team members (excluding *SB*) at times (*"communications bothered me the most"*) and often had to probe further on communicated topics. As an example, he described how members would query him on missing, mismatched or individually subjective visual details in initial versions of his artwork that were generated from our group discussions. He saw that the extra time for his rework had impacted the team's progress (*"this caused delays to the team"*).

Q2. and Q3. *SA* identified (hands-on) 'demonstrations' to be the best approach for him to learn about AR (*"I think that it is a better approach than only watching videos"*). He described his exchanges with *SB* to develop artwork for the mini-games and the sharing of his ideas during discussions to be his contributions towards the project, and acknowledged his inputs of ideas during group meetings as being part of the collaboration process that had occurred (*"… I provided views on game contexts that were eventually effected as changes (by the team) in the project."*).

Summary of responses for Student-Artist B

Q1. *SB* did not sense that the team had been experiencing any real troubling issues but mentioned that there were occasional difficulties for him to fully understand the other members (referring to slight differences in language across disciplines). He also felt that (project) changes were effected rapidly.

Q2. and Q3. *SB* successfully recalled and identified all the sources of 'knowledge empowerment' that were supplied to both student-artists – academic papers, web video examples and actual practical playtesting of games and AR interaction concepts during project development. He however also included the 'group meetings' as a source of learning for himself. *SB* attributed that these sources were equally important for him to learn about AR.

SB claimed ownership of the mini-games' designs and game scripting tasks, and included his inputs during the group meetings as one of his contributions to the project through the following transcribed statement - *"I sometimes gave comments during our meetings. In particular these were the occasions when we discussed which (game concepts/types) were better suited for specific locations (referring to the distribution of the game activities across the physical game site). For instance, (I suggested) that some game types might be better suited for certain locations."* He eventually described processes that happened through the collective efforts of the group and exchanges – i.e., *"The splitting of the map into 'treasure-map-like' pieces was also something that* ***we did together****."*

Interpreting responses for Q1

We want to see if the student-artists had noticed either the co-assignment (Section 3.3) or rescheduling (Section 4.1.1) incidents. To answer this question, they must explicitly identify *SA*'s work progress during the project as the main cause for these events.

Result - Citing personal experiences, both student-artists reported that they had faced communication issues with team members during the case of 'The Jackson Plan'. It turned out *SA* himself identified that this problem had impacted the team's schedule.

Interpreting responses for Q2

We want to highlight that 'knowledge transfer' (from the researchers) had enabled the student-artists to work with AR media. To answer this question, the student-artists must associate or recognize that their self-identified areas of work as contributions to the group-based AR design activities, and final outcomes.

Result - The student-artists recognized and related their own respective inputs (work and ideas) as part of the project's AR design and execution processes.

Interpreting responses for Q3

To answer this question, the student-artists must describe some sense of mutual exchanges of work and ideas between themselves and the other team members that had contributed to the project's design processes and/or final outcomes.

Result – Both the student-artists cited their contributions of ideas in several of the group-based activities (discussions, meetings, actual design processes and playtesting sessions).

Figure 12. The Singapore River: Play site for "The Jackson Plan".

5.3 Informing Design and HCI

Situated contexts that are exemplified through storification and the consideration of technological limitations seem to be able to justify design decisions of location-based HAR game attributes. In our case, the authors sought to create a learning experience of representing 'living in the past' in the historical context of "The Jackson Plan" (Figure 13) that would allow a pair of players to collaboratively 'interact' with contextual information at given points of location-induced opportunities during gameplay. This inspired a HAR user interface where visual and tangible game controls have been embedded to support collaborative communication designs. We will next look at how aspects of the design outcomes from the recent experiences gained through the development of "The Jackson Plan" may be used to inform interaction design in HCI ([45]).

Figure 13. Reflecting the Past in Present[11].

5.3.1 Digital Evolutions

Amidst an evolving landscape of digital cultures and the public's notion of digital interaction, [20] introduced a categorization of classes of digital interaction to use video game culture as a metaphor to redefine local digital culture by the degree of physical interaction, *'liminal'* as the less physical-digital (i.e. using a conventional gamepad's button push to represent the metaphor for kicking a ball), and *'transitive'* as the more physical-digital (i.e. physical computing systems such as Nintendo's Wii[12] where user's actions are always an integral part of the interaction itself). In their work, user-to-media relationships are drawn by intersecting *luminal/transitive* interactions to *control-* (the computer science approach of user to medium focus) and *communication*-based (human communication theory of user to user focus) interactions, producing the definitions of ***operational*** (combination of *control-communication* and *liminal-transitive* interactions) and ***relational*** (combination of *communication* interaction with both medium and dialogic interactions) **senses of interactions**. These definitions are used to describe a piece of interactive media (art installations, video games, and new media) according to the degree of **user's control**, **sense of involvement** and **primary function** (i.e. *control-based transitive interaction*, or *communication-based liminal interaction*, etc), noting that the most crucial aspect of this classification is that digital culture cannot be considered without concerning socially-motivated local digital culture (which is multi-variate and difficult to define).

---

[11] Original postcard from the *Lim Kheng Chye's* Collection (archstudio@pacific.net.sg)

[12] http://www.nintendo.com/wii/

5.3.2 Interpretations

In consideration of the **core design** (relational) and **purpose** (operational) of the proposed player-interactions in the two mini-games' designs, we describe using [20]'s multi-cultural definitions of interaction that these are situated on the very point of intersection between *liminal-transitive* and *control-communication*-based interactions. Being on the crossroad juncture, apart from bearing all the four traits of interactions, requires an instilled **equinoctial sensitivity** in the *media creator* for its development; the metaphor of an 'equality of light and darkness' has been used to associate the encapsulated understanding of technologies through the knowledge of their strengths and limitations. We position that both student-artists had acquired this 'sense' through their own acknowledgements (during the in-depth interviews) that they fused AR and art (game design) knowledge into this project's development.

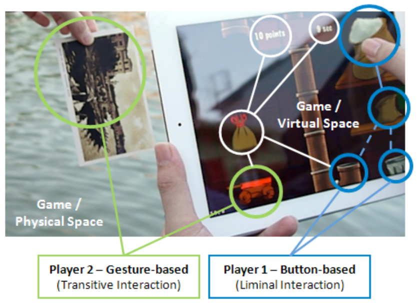


Figure 14. Interpreting Mini-Game 1.

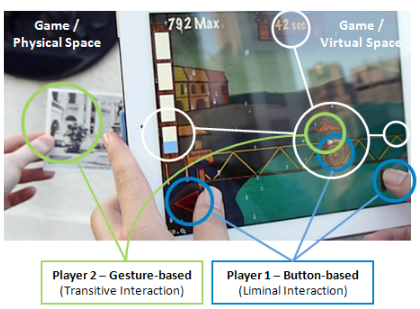


Figure 15. Interpreting Mini-Game 2.

Both the user interfaces for the HAR mini-games (described in Section 4.2) offer combined ***liminal*** **and** ***transitive*** **interaction** features in a single cross-media game space ([12]) that are bound by *action and reaction mechanisms* (*control-based interactions*) and *co-located*-players' *awareness of one another* ([21,23]) (*communication-based interaction*) to collaborate and overcome common game goals, i.e. Player 1's moves are *liminal* (button-based) while Player 2's moves are *transitive* (physical-based) but they are dependent on each other's actions and intercommunications to win the mini-games and advance in the LBG as a common goal, as in (Figure 14) and (Figure 15). Featured game interaction tie-ins in the user interface (i.e. the physical AR card marker) may be replaced or redesigned with other technological features or game mechanisms such as other digital sensing and identification technologies (including location-inference techniques, and in the near future, gesture recognition and projection features as well). The design of this user interface has also factored significant real-life operational conditions from its intended use-contexts (Section 2.2.3), such as the pragmatic need to co-locate children-players in closer proximity when an educational LBG is run by a single moderator in traffic-laden urban environments, and (trying to) retain children's attention on the specific task(s). **Equinoctial sensitivity** is thus also about crafting practicality in experiences.

5.4 Contribution

Practice-led research in arts and sciences (technology) is always propagated by a highly responsive and iterative exchange where new insights are quickly fed back into the development process to foster the co-evolutionary processes that happen in tandem within the collaboration [3] for all the parties involved. Technology use then yields new answers that may lead to the transformation of existing forms and traditional practices across disciplines. Ensuring that materials from every participant are usable is a major challenge in a co-creativity process. Working with student-artist collaborations can be successful when critical issues are properly identified and addressed despite rapidly evolving and changing project requirements [2], which this paper can be said to be a witness to.

The combined (selective) artistic outcomes of the two student-artists who worked in the interdisciplinary environment have also informed an interaction design for a collaborative co-located single shared interface for an outdoor location-based HAR game. Apart from gaming and edutainment, we foresee that it can be useful for creatively supporting user experiences in outdoor training, advertising and tourism applications.

6 Conclusion

We see the roles of the student-artists in "The Jackson Plan" as a successful co-creativity execution of artistic intimacies with intertwined interdisciplinary AR knowledge. Future work for this research will be to explore communication issues in the co-creativity processes of interdisciplinary AR media design.

As the ISMAR-S&T and ISMAR-AMH communities both seek for new blooms of inspirations and perspectives to innovate AR user experiences from, it is perhaps also a good time and opportunity for us to provocatively reflect on how we may as harbingers ignite co-creativity processes together.

Acknowledgements

This research is partially funded by project no. WBS R-705-000-025-271, a grant from the National Research Foundation through the Ministry of Education of Singapore, and project no. WBS R-705-000-029-592, an industry research grant from ST Electronics (Info-Software Systems).

We would like to thank the School of Design, Singapore Polytechnic for their support and interest in our research projects over the years, and to DGDD students *Lim Hong Kwan* and *Chen Yuyang* for working on "The Jackson Plan".

References

[1] S. Jones, "A Systems Basis for New Media Pedagogy," *Leonardo*, 44(1), The MIT Press, 2011, pp. 88-89.

[2] S.U. Ahmed, "Developing Software-Dependent Artwork: Artist and Software Developers' Collaboration," *Leonardo*, 45(1), The MIT Press, 2012, pp. 92-93.

[3] E. Edmonds and M. Leggett, "How Artists Fit into Research Processes," *Leonardo*, 43(2), The MIT Press, 2010, pp. 194-195.

[4] K. Woolford, A.F. Blackwell, S.J. Norman, and C. Chevalier, "Crafting a Critical Technical Practice," *Leonardo*, 43(2), The MIT Press, 2010, pp. 202-203.

[5] H. Papagiannis, "The role of the artist in evolving AR as a new medium," *Proc. of ISMAR-AMH*, IEEE, 2011, pp. 61-65.

[6] L. Candy and E. Edmonds, "Modeling co-creativity in art and technology," *Proc. of 4th conference on Creativity & Cognition*, ACM, 2002, pp. 134-141.

[7] E. Edmonds and L. Candy, "Relating Theory, Practice and Evaluation in Practitioner Research," *Leonardo*, 43(5), The MIT Press, 2010, pp. 470-476.

[8] C. Rust, J. Mottram and J. Till, "Review of Practice-Led Research in Art, Design & Architecture", Arts and Humanities Research Council, Bristol, 2007. <www.ahrc.ac.uk/About/Policy/Documents/Practice-Led_Review_Nov07.pdf>

[9] D.A. Schön, *The reflective practitioner: How professionals think in action*, Basic books, 1983.

[10] J. Meyer, L. Staples, S. Minneman, M. Naimark and A. Glassner, "Artists and technologists working together (panel)," *Proc. of UIST*, ACM, 1998, pp. 67-69.

[11] S. Jones, "A Systems Basis for New Media Pedagogy," *Leonardo*, 44(1), The MIT Press, 2011, pp. 88-89.

[12] R.K.C. Koh, H.B.-L. Duh and J. Gu, "An integrated design flow in user interface and interaction for enhancing mobile AR gaming experiences," *Proc. of ISMAR-AMH,* 2010, pp. 47-52.

[13] Y.-N. Chang, R.K.C. Koh, and H.B.-L. Duh, "Handheld AR games - A triarchic conceptual design framework," *Proc. of ISMAR-AMH*, 2011, pp. 29-36.

[14] E. Barba, B. MacIntyre, and E.D. Mynatt, "Here We Are! Where Are We? Locating Mixed Reality in The Age of the Smartphone," *Proc. of the IEEE*, 100(4), 2012, pp. 929-936.

[15] W. W. Gaver, "Technology affordances," *Proc. of CHI*, ACM, 1991, pp. 79-84.

[16] H.B.L. Duh, C. Chien-Hsu, C.C.C. Su, R.K.C. Koh, "An intuitional interface for invocation of Chinese painting," *Proc. of ISMAR-AMH*, IEEE, 2009, pp. 53-54.

[17] N. J. Bidwell, and J. Holdsworth, "Battleship by foot: learning by designing a mixed reality game," *3rd Australasian conference on Interactive entertainment*, Murdoch University, 2006, pp. 67-74.

[18] R.D. Duke, "A Paradigm for Game Design," *Simulation and games*, 11, 1980, pp. 364-377.

[19] F. Bellotti, R. Berta, A.D. Gloria and V. Zappi, "Exploring gaming mechanisms to enhance knowledge acquisition in virtual worlds," *Proc. of Digital Interactive Media in Entertainment and Arts (DIMEA)*, ACM, 2008, pp. 77-84.

[20] T. Woo, K. Wohn and N. Johnson, "Categorisation of New Classes of Digital Interaction," *Leonardo*, 44(1), The MIT Press, pp. 90-91.

[21] J. Stewart, E.M. Raybourn, B. Bederson, A. Druin, "When two hands are better than one: enhancing collaboration using single display groupware," *Proc. of CHI*, ACM, 1998, pp. 287-288.

[22] M. Billinghurst I. Pouprev, H. Kato and R. May, "Mixing realities in shared space: An augmented reality interface for collaborative computing," *IEEE*, vol. 1643, 2000, pp. 1641-1644.

[23] Y. Xu, M. Gandy, S. Deen, et al, "BragFish: exploring physical and social interaction in co-located handheld augmented reality games," *Proc. of ACE*, ACM, 2008, pp. 276-283.

[24] J. Mason, *Researching your own practice: The discipline of noticing*, Routledge, 2002.

[25] Ministry of Education, Curriculum Planning and Development Division (Singapore), *From Settlement to Nation, Pre-1819 to 1971*, EPB Pan Pacific, 2007.

[26] S. Giiven and S. Feiner, "Visualizing and navigating complex situated hypermedia in augmented and virtual reality," *Proc. of ISMAR, 2006* pp. 155-158.

[27] D. Frohberg, "Mobile Learning is Coming of Age: What we have and what we still miss," *DELFI 2006: Die 4. e-Learning Fachtagung Informatik der Gesellschaft, für Informatik*, Darmstadt, 2006, pp. 327-338.

[28] B.H. Thomas, "Challenges of making outdoor augmented reality games playable," *Proc. of 2nd CREST Workshop on Advanced Computing and Communicating Techniques for Wearable Information Playing*, Nara, Japan, 2003.

[29] S. Feiner, B. Macintyre and D. Seligmann, "Knowledge-based augmented reality," *Commun. ACM*, 36(7), 1993, pp. 53-62.

[30] S. Akkerman, W. Admiraal, and J. Huizenga, "Storification in History education: A mobile game in and about medieval Amsterdam," *Computers & Education*, 52(2), 2009, pp. 449-459.

[31] J. Martin, "Gaming and Reframing Experiences with Place-Based Inquiry," *International Congress of Qualitative Inquiry*, University of Illinois at Urbana-Champaign, 2008, pp. 14-17.

[32] J. Wither, R. Allen, V. Samanta, J. Hemanus, T. Yun-Ta, R. Azuma, W. Carter, R. Hinman and T. Korah, "The Westwood Experience: Connecting story to locations via Mixed Reality," *Proc. of ISMAR-AMH*, 2010, pp. 39-46.

[33] S. Dow, J. Lee, C. Oezbek, B. MacIntyre, J.D. Bolter and M. Gandy, "Exploring spatial narratives and mixed reality experiences in Oakland Cemetery," *Proc. of ACE*, ACM, 2005, pp. 51-60.

[34] M. Montola, J. Stenros and A. Waern, *Pervasive Games: Theory and Design*, Morgan Kaufmann Publishers Inc., 2009.

[35] E. Ju, and C. Wagner, "Personal computer adventure games: their structure, principles, and applicability for training," *SIGMIS Database*, 28(2), ACM, 1997, pp. 78-92.

[36] R. Ballagas, A. Kuntze, and S. Walz, "Gaming tourism: Lessons from evaluating rexplorer, a pervasive game for tourists," *Pervasive Computing*, Springer, 2008, pp. 244-261.

[37] C.A. Lindley, "Game space design foundations for trans-reality games," *Proc. of ACE*, ACM, 2005, pp. 397-404.

[38] A. Oulasvirta, E. Kurvinen, and T. Kankainen, "Understanding contexts by being there: case studies in bodystorming," *Personal and Ubiquitous Computing*, 7(2), 2003, pp. 125-134.

[39] S. White, S. Feiner, "SiteLens: situated visualization techniques for urban site visits," *Proc. of CHI*, ACM, 2009, pp. 1117-1120.

[40] D. Wagner, "History of mobile augmented reality," *Communications*, 2009, pp. 1-21.

[41] Y. Xu, E. Barba, I. Radu, M. Gandy, R. Shemaka, B. Schrank, B. MacIntyre and T. Tseng, "Pre-patterns for designing embodied interactions in handheld augmented reality games," *Proc. of ISMAR-AMH*, IEEE, 2011, pp. 19-28.

[42] W. Broll, J. Ohlenburg, I. Lindt, I. Herbst and A.-K. Braun, "Meeting technology challenges of pervasive augmented reality games," *Proc. of 5th ACM SIGCOMM workshop on Network and system support for games (NetGames '06)*, ACM, 2006, Article 28.

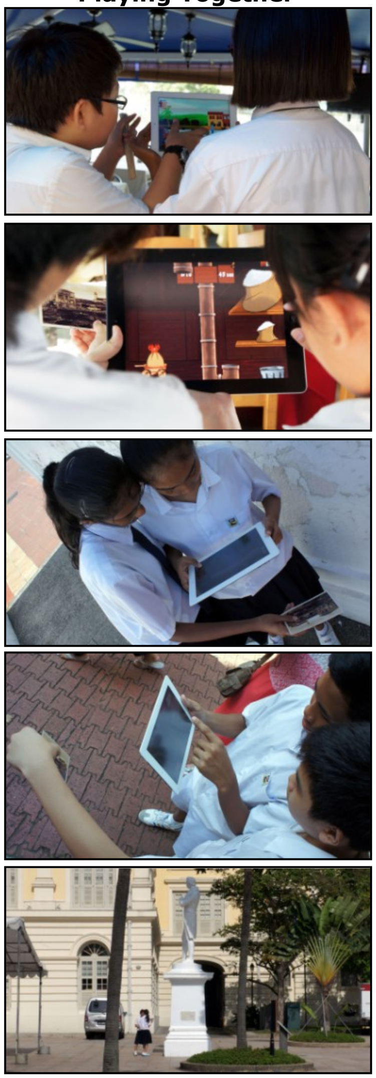
[43] N. Lambert, "From Imaginal to Digital: Mental Imagery and the Computer Image Space," *Leonardo*, 44(5), The MIT Press, 2011, pp. 439-443.

[44] T. Olsson and M. Salo, "Narratives of satisfying and unsatisfying experiences of current mobile augmented reality applications," *Proc. of CHI*, 2012, pp. 2779-2788.

[45] J. Zimmerman, J. Forlizzi, and S. Evenson, "Research through design as a method for interaction design research in HCI," *Proc. of CHI*, 2007, pp. 493-502.

Playing Together: Supporting Children-Played Outdoor Location-based Handheld Augmented Reality Game Deployments

"Playing Together"



Raymond Koon Chuan KOH
Keio-NUS CUTE Center / ECE /
Division of Industrial Design,
National University of Singapore,
21 Heng Mui Keng Terrace,
I^3 Bldg, Singapore 119613
salmonbowl@gmail.com

Henry Been-Lirn DUH
Keio-NUS CUTE Center / ECE,
National University of Singapore,
21 Heng Mui Keng Terrace,
I^3 Bldg, Singapore 119613
duhbl@acm.org

Cheng-Ho CHEN
Keio-NUS CUTE Center,
National University of Singapore,
21 Heng Mui Keng Terrace,
I^3 Bldg, Singapore 119613
idmcch@nus.edu.sg

Yun-Ting WONG
Keio-NUS CUTE Center,
National University of Singapore,
21 Heng Mui Keng Terrace,
I^3 Bldg, Singapore 119613
deidrawong@nus.edu.sg

MobileHCI'12, September 21–24, 2012, San Francisco, CA, USA.
ACM 978-1-4503-1443-5/12/09..

Abstract
Real-world user issues in the deployments of location-based games with children have been factored in a proposed dual-player user interface design as a co-located single shared display with combined cross-media interactions. The use case is an outdoor location-based educational handheld augmented reality game.

Author Keywords
Handheld augmented reality, co-located collaboration, single-shared display, location-based game

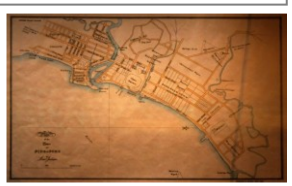
ACM Classification Keywords
H.5.1. [Information Interfaces and Presentation]: Multimedia Information Systems – Artificial, augmented, and virtual realities

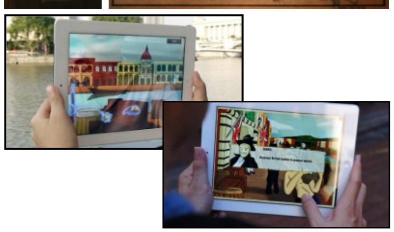
General Terms
Design, Experimentation

Introduction
Actual deployments of location-based games that involve multiple children-users may often implicate safety (urban traffic) and user-attention issues. In the

"The Jackson Plan" LBG Specifications

The learning experience of a lower secondary history textbook chapter - *Sir Thomas Stamford Raffles'* founding of modern Singapore in the year **1819** is presented (on Apple iPad 3rd Gen.) as a location-based educational game experience with HAR features across landmarks along the *Singapore River*. It features as an adventure game ([6]) trail, the use of a narrative and HAR effects (*geo-registered panorama art, photo-taking activity, physical feature recognition / vision-based AR*) to bridge historical contexts to evocative places [7].





use case of an educational location-based game (LBG), we have taken an initial attempt to address this specific issue for two student-players by proposing a single shared display user interface (UI) with a unique combination of synchronized *'transitive'* (more physical-digital) and *'liminal'* (less physical-digital) ([1]) handheld augmented reality (HAR) game interactions. These interactions are respectively played by the two players in a shared game space to achieve common game tasks. Such an interaction design demands converged attention and players' physical co-location as a requirement for the intended gaming collaboration (or competition) to take place.

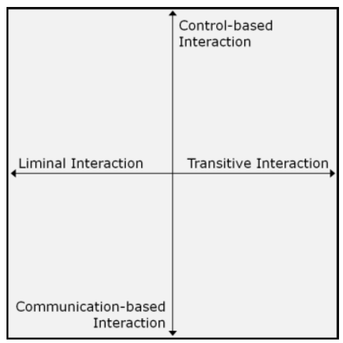


Figure 1: [1]'s definitions of interactions.

Related Work

• [1] introduced a classification of digital interactivity by examining local digital culture. Using video game culture as the interpreting metaphor, user-to-media relationship are drawn as **'*control-*'** (computer science approach of user to medium approach) and **'*communication*'**-based interactions (human communication theory of user to user focus). The degree of physical interaction is presented as **'*transitive*'** (more physical such as gestures) and **'*liminal*'** (less physical such as using joy-pad buttons to represent certain actions such as kicking a ball) interactions (Figure 1). These definitions are used to describe a piece of interactive media according to combinations of these four interactions as **operational** (intersection of *control-communication* and *liminal-transitive*) and **relational** (combination of communication interaction with both medium and dialogic interactions) senses of interactions.

• Safety is a priority while using Augmented Reality (AR) in an outdoor setting. Early outdoor mobile AR game systems that utilized Head-Mounted Displays raised "information tunneling" issues where more attention is spent on the information rather than on the physical world. For one such system, a second person is inserted alongside the player during gameplay [2].

• A 'single display groupware' software model supports peer-to-peer collaborations, converges children's attention, and promotes task solving in educational settings for co-located children-users [3].

• A shared augmented play space that is tightly registered with the physical world promotes physical awareness through conveyed senses and perceptions through co-located players' movements and their meanings in gaming context [4].

• The various input/output channels of digital and sensor technologies that can be found in smart handheld devices (i.e. mobile phones, handheld computers, etc) can be mapped to complement game mechanics for real-world 3D interactions to be designed into 2D screen spaces (and vice versa) as cross-media design for mobile AR [5].

User Interface Description

As a proof of concept, two game segments of "The Jackson Plan" LBG (side bar, page 2) experience have

Mini-Games' Descriptions

• **"Rice-Packing"**: Players collaboratively pack sacks of rice in corresponding steps for '**packing**' (played by **Player 1** using an on-screen UI to perform sequentially-ordered moves), and '**catching**' (played by **Player 2** using fixed orientations of a physical card marker to trigger appropriate 'basket' changing to catch falling colored-sacks in time). Only complete cycles of the two players' actions count towards scoring and 'mis-packed sacks' (those that used broken sacks) are to be thrown away (Figure 2).

• **"Rain-Sheltering"**: **Player 1** maneuvers a virtual cart of cotton stock by using an on-screen UI. **Player 2** uses a physical AR card marker to control a virtual umbrella to shelter **Player 1**. They are to keep the cotton dry while crossing the bridge. Random obstacles (wind, twigs and rain) obstruct the players' progress (Figure 3).

been structured and designed as mini-game challenges that utilize HAR features (side bar, page 3). In them, the nature of the game design and mechanics requires the two students-players (intended users) to collaborate in order to win. Game contexts and design elements are drawn from the subject matter (educational learning concepts from the academic syllabus) and from real-world places (contexts). With reference to Figure 2 and Figure 3, both the UIs for the two HAR mini-games offer combined *liminal* and *transitive* interaction features in a single cross-media game space that is bound by *action* and *reaction* mechanisms (***control-based interactions***), and *co-located*-players' *awareness* (***communication-based interactions***) to overcome common game goals. Player 1's moves (Blue Circles) are *liminal* (using buttons to represent actions) while Player 2's moves (Green Circles) are *transitive* (using gestures performed with a physical AR card marker to translate movements), but they are dependent on each other's actions and intercommunications to win the mini-games and advance in the LBG (White Circles). A single shared display that may be presented using either a 'private'/split-screen (Figure 2) or 'common' (Figure 3) space design shows the game status. Virtual obstacles hinder the players' progress. Game interactions and challenges are play-tested and iteratively adjusted by designers and developers during development.

Discussion and Limitations

The current design provides a few provocative insights for meaningful discussions. Using [1]'s interactivity classification, this UI design is said to be situated at the point of intersection of all four interactions (Figure 1), thus bearing all the associated traits.

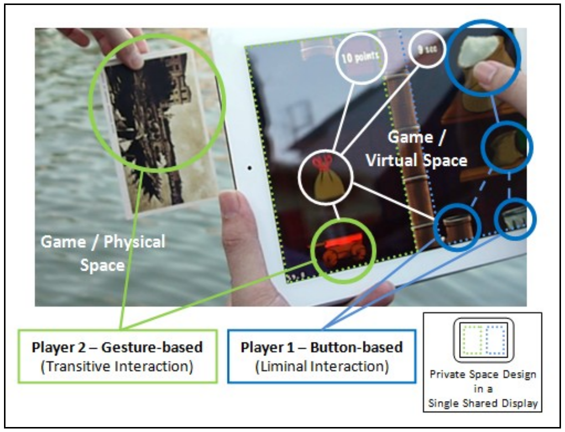


Figure 2: "Rice-Packing" Mini-Game.

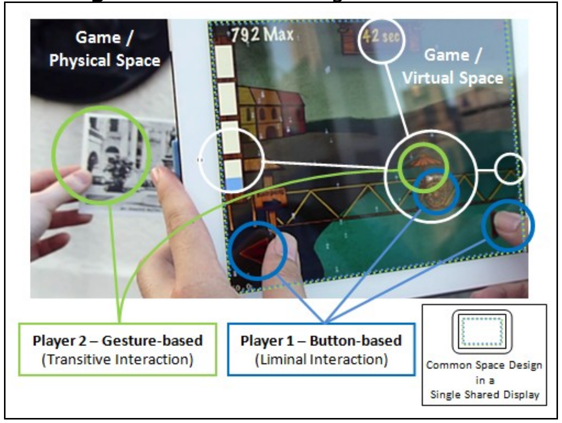


Figure 3: "Rain Sheltering" Mini-Game.

The dual-player design of this UI has considered significant real-life **operational** and **relational** conditions from its intended use-contexts with children-players that have been mentioned earlier. Co-locating children together helps an educational moderator to regulate their overall movements when gaming (children may otherwise stray off or get distracted). We

Future Work: Place-based AR Design for Informal Touristic Learning

Literature has identified the significance of learning and play (novelty, curiosity and exploration) as motivations for people to want to travel. [8] suggested that informal and unplanned settings may present learning opportunities within tourism (as to 'educational tourism' which is structured and systematic such as 'The Jackson Plan' heritage trail). Beyond supporting 'visitor study'-type ([8]) applications (i.e. heritage sites, museums, etc), one of the research plans is to extend the current work into place-based AR design for supporting informal touristic learning. Such (H)AR UIs may instead be crafted with more investigative features that are enabled by embedded multi-sensory hardware in HAR devices to promote active socializing and environmental explorations during pleasure travels.

argue that the 'transitive' interactions in this design help to maintain an awareness of the physical world by having one player to intermittently look out of the screen space. In a preliminary usability assessment, 36 children (18 student pairs taking the History subject) completed the predesignated trail without any prompting (to stay together) by the accompanying moderator (side bar, page 1). During the post-game interview, the majority of the children described the mini-games to be fun and enjoyable. The current work also supports cross-media augmentations, which are useful for considering HAR media design ([5]) as the game mechanics in this case study can be easily replaced with alternative digital sensor and identification technologies to complement or enrich HAR interaction experiences. Apart from gaming and edutainment, we see applicability in supporting training, advertising and tourism. Limitations include,

- Only two deployment issues have been addressed.
- The current approach only supports two players and may not fit all game genres.
- Game mechanisms and designed affordances ([4]) have to be thoroughly thought out and play-tested.
- Only handheld devices with a relatively large screen display can support such a user interface design.
- Formal user evaluation is ongoing.

Conclusion

We see that design opportunities are present for user interfaces that support children-played location-based HAR game deployments in outdoor contexts.

Acknowledgements

This research is partially funded by the National Research Foundation through the Ministry of Education of Singapore *(WBS R-705-000-025-271)*, and by ST Electronics (Info-Software Systems) *(WBS R-705-000-029-592)*. Special thanks to Outram Secondary School for participating in the user study, and to Chen Yuyang and Lim Hong Kwan from Singapore Polytechnic for their involvement in game design and development.

References

[1] Woo T, Wohn K, Johnson N. Categorisation of New Classes of Digital Interaction. *Leonardo*, 44(1), The MIT Press, (2011), 90-91.

[2] Thomas BH. Challenges of making outdoor augmented reality games playable. In: *2nd CREST Workshop on Advanced Computing and Communicating Techniques for Wearable Information Playing*, (Nara, Japan, 2003).

[3] Stewart J, Raybourn EM, Bederson B, Druin. When two hands are better than one: enhancing collaboration using single display groupware. In: *Proc. of CHI*, ACM, (1998), 287-288.

[4] Xu Y, Gandy M, Deen S, et al. BragFish: exploring physical and social interaction in co-located handheld augmented reality games. In: *Proc. of ACE*, ACM, (2008), 276-283.

[5] Koh RKC, Duh HB-L, Gu J. An integrated design flow in user interface and interaction for enhancing mobile AR gaming experiences. In: *Proc. of ISMAR-AMH*, IEEE, (2010), 47-52.

[6] Ju E, Wagner C. Personal computer adventure games: their structure, principles, and applicability for training. *SIGMIS Database*, 28(2), ACM, (1997), 78-92.

[7] Wither J, Allen R, Samanta V, et al. The Westwood Experience: Connecting story to locations via Mixed Reality. In: *Proc. of ISMAR-AMH*, IEEE, (2010), 39-46.

[8] Mitchell, R. D. Learning Through Play and Pleasure Travel: Using Play Literature to Enhance Research into Touristic Learning. *Current Issues in Tourism*, 1(2), (1998), 176-188.

Handheld AR Games - A Triarchic Conceptual Design Framework

Yu-Ning Chang*
Institute of Communication Studies
National Chiao Tung University, Taiwan

Raymond Koon Chuan Koh+
Interactive & Digital Media Institute / ECE
National University of Singapore

Henry Been-Lirn Duh+
Interactive & Digital Media Institute / ECE
National University of Singapore

ABSTRACT

The rapid development of handheld Augmented Reality (AR) technologies has raised profound interests in the design of handheld AR games. Studies in this area however did not draw attention explicitly on design concepts, especially in the possible exploitation of their inherent characteristics to impact game experiences. Based on literature review, this paper identifies the game elements that are designed based on, or around the definitive advantages and/or limitations of handheld AR as a form of pervasive technology that may affect game play experiences. Handheld AR game experiences are examined and can be described through a proposed triarchic interplay of coherent associations comprising of fundamental system, interaction and application levels. Future work will include intricate studies on game design for handheld AR games, so as to extend the current findings with other integrative game design and technological elements.

KEYWORDS: Handheld augmented reality game, Game design, Seamful design.

INDEX TERMS: D.2.10 [Software]: Design — Methodologies

1 INTRODUCTION

With the proliferated capabilities in 3D graphics, advanced processors and display technologies, there are now increasing numbers of AR technology-based games available for mobile phones. Earlier related studies have mostly focused on the introduction in evolving technologies and emphasized less on the inherent impact on game design while taking the extents of the technologies into account.

Game experiences that players have are influenced by game mechanics. Before understanding them, it is important to realize how the applied technologies are relevant to or affect the process of game design. As a platform, handheld devices are minimally intrusive, socially acceptable, readily available and highly mobile [1], which can support compelling pervasive games ([2]).

AR technologies that are based on the less costly, simpler and physically-lighter handheld devices possess several advantages that can enhance game play, such as the provision of a common digital game space for players to share a sense of social and/or physical presence, and allowing players to control the game by manipulating physical objects that are linked using computer vision technologies (i.e. visual recognition systems). Conversely, handheld AR technologies encounter design issues that may interrupt or reduce the game flow that is experienced, including unstable performances due to fluctuating mobile connectivity and limited input and output options in devices that hinder natural.

This paper introduces the concept of a potential interplay between system, interaction and application levels that subsist in previous handheld AR game research, and identifies key characteristics of handheld AR technologies that may affect game experiences. In the next section, we first review related work in handheld AR games, game design and seamful design ([3]). Section 3 presents an analysis on selected handheld AR games, while Section 4 describes the game elements in them that are drawn from the literature review. Finally, we conclude with a proposed game design framework for handheld AR games which is motivated by the seamful design approach.

2 RELATED WORK

This section comprises of three parts – an overview of current state of development for handheld AR games, a comprehensive survey on game design, and the relevance of seamful design.

2.1 Handheld AR Games

AR technology allows users to see the real world with superimposed virtual objects with the following three characteristics - combination of real and virtual, real-time interaction, and registration in 3D [4].

In this paper, the definition of "handheld devices" includes digital dictionary, Personal Digital Assistants (PDAs), mobile phones, tablet personal computers, and portable media players. From year 2000 onwards, the use of pervasive handheld devices has opened up new avenues of use for AR applications. From a technical perspective in a software engineering context, a handheld AR application usually consists of four key components [5] - AR library, graphics and multimedia functionalities, networking support and a game application framework.

The AR library performs low-level work to 'talk' to the operating system and access low-level API calls to obtain raw video data from the device's camera stream in order to perform image processing tasks and to track feature points. This is an essential component for almost every image-based handheld AR (game) application. For research purposes, two image-based AR libraries are commonly used in handheld AR and game projects, ARToolKit [6] (which is available for various handheld platforms including mobile phones [7] and PDA devices [8]), and Studierstube ES/STBtracker [9].

Graphics and multimedia functionalities include 2D/3D scene rendering, sound engine, sensor readings, multi-touch support, etc. The performance of 3D scene and object processing is a vital factor that affects a handheld AR game's efficiency. This processing is more demanding than what is typically required for a handheld game and consumes much of the available processing power, making it a challenge when implementing high level components. Optimizations of AR performance on the handheld platforms thus remain as a significant area of research. As handheld devices gradually feature a wider range of integrated sensors such as compass, interactive projections, high-resolution camera, GPS, accelerometer and Near Field Communication (NFC) technologies, these additional supplements can bring about

21 Heng Mui Keng Terrace, I3 Blg,#02-02-01,NUS, Singapore
119613/*aaietw@gmail.com +raymondkoh/eledbl@nus.edu.sg

IEEE International Symposium on Mixed and Augmented Reality 2011
Science and Technolgy Proceedings
26 -29 October, Basel, Switzerland
978-1-4673-0059-9/10/$26.00 ©2011 IEEE

new AR game experiences to users by the provision or integration of novel interaction opportunities with sensor data and contexts of players.

Network communication refers to digitally mediated communication ([2]) which is an essential feature for a complete handheld AR experience in collaborative, cooperative or competitive gameplays. It can consist of two devices that use either a Wi-Fi or Bluetooth connection for the game to be played (i.e. one device acts as the server and the other as a client, or in the case of a direct server connection by a single device, a client-server architecture may be used instead on any available wireless connection options (i.e. Wi-Fi/3G/3.5G/WiMax/GPRS/GSM) for the player to interact with other players such as in multiplayer online games or to access a remote server. Peer-to-Peer (P2P), a distributed application architecture for user-sharing of tasks and resources, is commonly used in handheld AR games for integrating social gaming features [10][11]. Network communication also allows access to external data and services (i.e., GPS tracking, cloud-computing systems, social media platforms).

A **game application framework** includes a variety of functionalities and features that can be used to build game structures, support interaction styles and establish or guide player behaviors [12]. The framework of the handheld AR game is mainly dependent on the game context which will be further discussed in the next subsection.

The *Invisible Train* [13] is an example of a typical handheld AR game that utilizes or exploits specific characteristics of AR technologies in order to design its game mechanics. The goal of this game is to steer a virtual train over a real wooden railroad track with other players in a cooperative or competitive mode. A PocketPC PDA with a 400MHz XScale processor is used as the game's hardware system. Interaction between players is supported using the relatively reliable Wi-Fi connection. A combination of AR library, graphics and multimedia functionality implementations allows players to enjoy a multi-sensory experience as if they are interacting with real objects. The experience is further enhanced through player-interactions via information exchanges using network support. From this example, it can be seen that it is important that a game appropriately takes collective advantage of the specific applied technologies, so that players can be closer involved in the game flow process through the intuitive supporting mechanisms that can be introduced.

2.2 Game Design

Games are systems of experience and pleasure; of meaning and narrative play; and of simulation and social play [12]. Game design is a process in which a game designer creates a game to be encountered by a player. Meaningful play emerges as a result and interaction occurs between players and game mechanics. An approach in game design is in the consideration of playability that is provided, so as to understand the important game elements that constitute the game experience. However, such an approach usually focuses more on issues such as game mechanics, game interface design and game-player interaction, rather than on the aspects of technology that may impact the game experience [14].

Understanding technologies is fundamental to create a good user experience. At a basic level, handheld AR games can be coupled with common technological features in their design, including the combination of real and virtual spaces to create engaging real-time interaction opportunities. Potentially novel gaming experiences can be presented through games that integrate multiplayer support. Specifically, shared spaces in AR can be crafted to provide a common environment for 'player-sensing' and player-to-player interaction rather than to only present a simple on-screen experience, and this is so even if players may be physically apart [2]. This paper relates a fundamental understanding of how technologies can be relevant in games to support game flows, and this will be discussed in detail in Section 4.

2.3 Seamful Design

AR technologies (which include handhelds) when based in or around physical environments exhibit various characterized differences (including the uncertainties and inaccuracies in network and tracking performances respectively) that Weiser [3] termed as "seams" through his concept of "seamful design" (being "literally visible, effectively invisible"). Seamful design can be defined as a design approach where the internal functions of a technology are intentionally made obvious to its users, and the technology itself is a utilized design resource instead of an encumbrance. Game designers employ this approach to work around such seams to maintain the overall interaction flow between game mechanics and players, and yet retain the richness of each interaction tool. Possible resources for game design are characterized in Section 4.

For example, one of the prominent characteristics of handheld AR games is mobility. As handheld AR devices are almost entirely mobile, access to them may hence be non-continuous or limited because of the environmental factors that the devices are being used in. Players are likely to drop in and out of games relatively quickly as a result. For example, playing a game while waiting for a bus or train can be disrupted when it arrives, or the loss of mobile (telecommunication) signal onboard a moving transportation that is travelling through a tunnel can break established network connections for online mobile games. Casual games in this case can be one of the suitable design implementations to address such seam because they are short session games that are easy to play [15], which can be ideal for people on the move. The consideration and use of a seamful design approach can be factored in the associated game experience design process for handheld AR games so that they may still be played under various restrictive environmental conditions, or bear mitigating or bridging measures to handle the seams that surface as a result of such sudden change(s).

2.4 Three levels of consideration

Centered on the issue of heterogeneity, game design for handheld AR games tends to specifically involve an interdependent underlying *system level* that coherently includes all the characteristics of the applied technologies. The *application level* is context dependent and can be multi-varied, such as in 'facilitating learning' and 'enhancing social interaction' for example. An *interaction level* is extrapolated from the interworking elements of the two levels (system and application) being associated in ascertained compatibility. That is, the matching of identified elements and/or areas in system and application levels firstly support appropriation(s) in varying degrees in handheld AR systems, and secondly, fulfill the primary purpose of the intended application. This matching can thus unveil interaction design level issues that should be considered and addressed in the handheld AR game design process.

The next section presents relevant game design components in consolidated handheld AR games, followed by a discussion on how these games have been designed with elementary aspects of game design that exploit the features or limitations of handheld AR technologies as definitive attributes in games.

3 METHOD

This study distills relevant reviewed publications as representatives for each associated category of design constitutions with respect to the three levels of consideration (Section 2.4). Moderation is performed through the consideration of the selected publications' exploitations of the nature and characteristics of handheld AR technologies, rather than focusing on the inherent generic game elements in them. According to [16], games ideally must have clear goals although their outcomes may be uncertain. Thus while achieving these goals what players would encounter can be interpreted as challenges that the games provide. Through game play, the sense of pleasure and satisfaction may be increased. The use of feature-enabling technological attributes, such as utilizing physical accelerometer-tilts to provide in-game character/object rotations, can intrinsically add on to this enrichment.

Table 1. Design levels for handheld AR games.

	Concept	**Issue(s) and measure(s)**
Application Level	*Social Interaction (example)*	* Enable social communication during game play through: Face-to-face collaborations/competitions (verbal / nonverbal communications), remote interactions for seamless unity of players. *Instill sense of social and/or physical presence [10].
	Learning (example)	* Show virtual content in physical spaces. *Allow collaborative learning via network communication. * Quick deployablility. * Easily accessible platform. *Induce physical exploration for knowledge inquiry.
	Contextual Information (environment)	*Foster explorative mobility of players during game play.
Interaction Level	*Manipulation*	*Assert physical affordances of associated input devices as interaction tools. * Enable control of virtual objects by tangible manipulation of physical attributes. * Maintain interaction flows to provide a more complete and engaging experience.
	Multi-sensory feedback	* Allow progressive task completions. * Instill awareness of technological limits via sustainable measures.
System Level	*AR system*	* Use of real-time overlaid 3D virtual objects in the real world. * Instill awareness of game states that are influenced by *slow/inaccurate tracking traits* and *lighting conditions* * Slow tracking: Avoid rapid button presses [11], sudden camera movements and intensive 3D graphics [7]. Technical loads should be balanced (i.e. use pause intervals such as load screens) and pacing should take into account the extent of tracking performance. * Handling uncertainties / Inaccurate tracking traits: *Pessimistic* to show only information that is correct, *cautious* to intentionally show inaccuracies, *opportunistic* to exploit inaccuracies [17]. *Lighting: Set controlled parameters (use flashlights to *improve lighting under dark conditions as a game scenario* ([18]).
	Network communication	*Uncertainties in wireless/co-located communication can employ game structure deliberations such as careful game location/timing selections, intentional hiding/revealing for players to adapt/exploit, incorporation into game structures (i.e. "hide in shadows", outside network coverage areas) [19].
	Form Factors	*Design focused activities for small screen display screens.
	Mobility	* Interruptability: Quickly resume or load the last saved game state. * Gameplay should be short [15]. * Instill contextual adaptability [2].

4 Results and Discussion

In the review of the selected games, several distinct characteristics of handheld AR technologies that are divided according to the *three levels of consideration* for handheld AR games are identified and highlighted in (Table 1).

4.1 The System Level

The fundamental level of game design is established using the features of applied technologies. The characteristics of handheld AR technologies that are closely related to game experiences notably include performances in tracking, lighting conditions, and network communication.

4.1.1 Handheld AR Systems

From a technological perspective, several prominent features may affect the overall gaming experiences. For example, interactive 3D graphics employed in the handheld AR games may intensify sensory immersion levels (one of the three gameplay experience models developed by [20]).

The majority of the selected handheld AR games make use of computer-vision marker tracking technologies to assist in the creation of game experiences. As an alternative to ordinary markers (i.e. square fiducial markers), [21][22][23] utilize natural features to aid the tracking systems.

In [21], players 'kick' the virtual football from the screens of handheld devices. The game system captures foot movement and then calculates the direction and speed of the ball to complete the game interaction. [22] is similar as it also uses physical body movements that are detected by the cameras of handheld devices to provide the game experience of throwing or dodging virtual cakes. [23] makes use of specific objects in the actual environment as virtual enemies that players must 'attack'. Feature matching is automatically performed when the predefined objects come under the purview of the handheld device. As part of the game mechanics, it is intentionally and seamfully designed that players have to center and maintain the handheld device's camera/screen on the virtual enemies (objects), or their energy levels will decrease. [24] presented three games that used circular markers to form novel game experiences. Virtual objects can be moved from one physical marker to another.

Seams of handheld AR can be used as resources for game design. Since screen displays are too small to have extended graphical views, games can be designed as focused activities. Game flows/experiences that may break under unsuitable/unstable operating conditions (i.e. due to poor lighting, sensitive tracking and disrupted wireless communication signals, etc) can instead feature *indicative parameters for player guidance* ([19]) establishments as mitigation measures.

4.1.2 Network Communication

The recent advent of advanced network communication technologies allows several functionalities to be used to enhance game experiences. For example, (device) mobility when coupled with network communication enables the instant sharing of locations through physical and ad-hoc activities as real-world interactions. With the facilitation of information exchanges in applications, network communication technologies enable player-interactions in games. In collaborative tasks for example, players are able to gain awareness of the presence of others and to engage in interaction activities through game mechanics. They can also share pieces of information through the communication support.

However, stability issues in network communication (and location) technologies such as inaccuracies, latencies and jitters pose as a key challenge when designing game mechanics. Applying the concept of seamful design, this nature of random fluctuations and uncertainties can be intentionally pegged to various levels of game task difficulty or be used in game systems when players have to seek for its features/constituents (i.e. to locate network hotspots). Hybrid systems that bear interchangeable client-server and P2P architectures allow players to share a consistent game experience that has a highly localized ad-hoc game play [19]. In addition, such adoption of disguising seams as game rules in a game's design can sometimes be more efficient than outright attempts to solve the problematic technical problems. Due to their unpredictable and random nature, they may be suitable as part of the game experience and rule conditions that lead or grant access to [2]'s notion of 'secretive interfaces' to support hidden manipulations in games (i.e. bonus game levels).

4.1.3 Handheld Devices

Handheld devices when used as a platform for AR games bear the inherent characteristics of mobility. They allow players to freely explore the real world and provide as means of physical interaction. Mobility however contains several issues in itself that are affected by contextual factors. Unfocused attention during game play (as one of the issues mentioned earlier in Section 2.3) that may occur due to disruptive interruptions is one such issue. [2] elaborated that time-consuming games set in persistent worlds are pervasive, and that such required effort (i.e., proper setting up/configuration of network and sensing technologies in order to intimately tie the game to the local settings of the different geographical locations ([19])) tends to force players to manage ordinary life and the game. The authors further added that players should be able to resume the last game state for an ongoing game, and be provided *variable pacing* for the game mechanics that they experience. The structuring of the possible game play duration and pacing for a handheld AR game should thus take into account the context of possible conditions of use (of the game) and compensate/mitigate for the anticipated intermittent breaks in game flows to allow for sustainable persistent play.

Form factors (of handheld devices) in personal interaction platforms can exert a certain extent of influence on game experiences. From the analyzed related cases, the presentations of visual effects and interactions for instance may be somewhat restrictive on the small screens of handheld devices. The best pervasive experiences hence should not take place on these small screens [2], and the small displays can instead be designed as a metaphoric microscope for observational purposes in the game world (as an example). However, an issue that is not within the scope of this study is that visual presentations can take place everywhere, meaning that contents can be viewed on the a wider variety of viewing surfaces and from various angles, both of which have been brought forth by forward technologies in handheld devices. Having a less restricted viewing mode allows interaction possibilities to extend beyond traditional displays (i.e. via embedded projection technologies), establishing new forms of intuitive engagement possibilities and reduces the sole reliance on direct device-based manipulations. One example is the use of natural gestures to perform specific actions in games. Form factors of handheld devices that can bring about revolutionary game experiences may also influence the consideration of seamful mitigation measures.

In addition, technical performances may be affected (i.e. slow screen refreshes or frame rates) by the limited hardware capabilities of a platform when the game is overloaded with processing power-consuming tasks that are required by the implemented features (i.e. fiducial marker recognition and real-time 3D renderings are both considered processor-intensive tasks for current handheld devices). The choice of such features should thus be considered from a seamful game design perspective so that the embedded sophisticated technologies are crafted to enhance and not encumber or degrade game experiences.

4.2 The Interaction Level

The second level of design involves the interaction layer which focuses on how players interact with the featured game mechanics.

4.2.1 Manipulation

Interaction in 3D environments can be namely differentiated as object manipulation, navigation and system control [25]. For handheld AR games, users can just like in the real world, interact with virtual objects by directly manipulating physical articles or attributes (they can be mapped to manipulative operations or tasks that are related to the virtual objects). *Properly applied metaphors in interfaces* for handheld devices are intuitive and easy to learn or use, and original behaviors can be performed or exhibited without any additional system assistance. This allows players to concentrate on achieving the game goals instead of having to use inefficient game interfaces.

4.2.2 Movement-based metaphoric interaction

Handheld devices can be considered as a rich *interaction tool* with six degrees of freedom [26]. Using inbuilt cameras, computer vision software and a reference coordinate system, sophisticated features such as physical movements (including kinematic measures), gesture recognition and screen position-tracking become possible. This not only mitigates awkward interaction styles (i.e. the pressing of small buttons on a compact keypad), but also leverages game play and provides fun experiences through physically embodied interactions.

One of the goals in the design of AR interfaces is to map appropriate metaphors to interaction design [27]. Selected games have adopted existing interaction metaphors: *Mobile Maze* [28] presented the use of a hand-tilted maze to control ball movements to create player enjoyment. In *Chinese Chess* [29] players interactively play the game through handheld devices' screens. A virtual chess piece is moved by pressing a physical button, resembling to the behavior of playing the actual game. In *Mobile AR Cooking Game* [30], players have to perform cooking related gestures based on real cooking mechanisms in order to complete game tasks. The in-game rules and interaction styles of *AR tennis* [7] are similar to the real game of tennis. An implicit metaphor to tennis racquets allow players to easily comprehend the game, if not already understood. An additional marker is attached on each phone's back (to detect players' presence) for the effective and appropriate adjustments of behaviors in the collaborative task.

4.2.3 Feedback

Feedback is the unique interaction that is experienced by the players as a game system response following executed action(s)

[12]. In the summarized handheld AR games, it can be seen that multi-sensory presentations may be effective measures to provide feedback to players' actions and how game states can be affected with technological performances.

Multi-sensory feedback provides players with a sense of being in the game and to understand what is happening in it, as in [7]. In [5], the use of supplementary audio playback and animations to create a multi sensory experience (using a virtual character) can engage players and be ideal for the screen estate-limited displays of handheld devices. An important game feature in [10] uses visual feedback to indicate broken game states that are generated from bad tracking performances, so that players can adjust themselves accordingly after seeing such indicators (an example of how technological characteristics of handheld AR that game designers make available for game design can be integrated).

4.3 The Application Level

The third level of game design refers to the applications of the characteristics of applied technologies during the process of game design.

4.3.1 Design with contextual information

Games on handheld devices can be designed to discern the players' context and then adapt the game experience that follows. In using contextual information randomly in an environment as game events to entice players to look for items in order to achieve objectives (as [2] termed as infinite affordances), one possible implementation is handheld location-based AR games. The *Treasure Hunt Game* proposed by [31] utilizes real-world locations in relative association to the game.

In *Mupeland Yard* [32], gaming takes place wherever the players are. Players play the two social role tasks of capturing the criminal as a detective, or escaping from the game environment as a criminal. Their locations are conceptually integrated using indicative hints on the virtual map. Location as a game element is designed in *POSIT* [33] for players to explore the buildings with handheld devices that show hints that are situated in the real world. This design idea is based on the use of the indexical environment to allow physical elements to represent themselves in the game [2]. Another similar work by [34] utilizes location-specific details as clues for seeking pictures to help reveal the treasure's location.

Players physically navigate in the *Team-Based Competitive AR Game* [35] where the goal is to protect and divert cows by physically moving specific markers. [36] designed a location-dependent *Treasure Hunting Game*. Players must explore the environment to collect clues for completing assigned tasks using GPS. Location information provided by handheld AR technologies to represent virtual game events in the real world connects the game and actual worlds.

4.3.2 Design for learning

Learning with games can possibly retain learners' attention spans and stimulate learning motivations. [37] defined games as learning processes because players are constantly seeking to understand the pattern of the game and repeat it until mastery is attained. As new technologies emerge, it is often necessary to understand the expansive and empowering possibilities that are thus offered in order to better design learning experiences.

Handheld AR games for learning [38][39] commonly use handheld AR technologies to induce the curiosity of the learners to perform associated actions. The *Art History Educational Game* [5] is an educational game for learning art history. Collaborative learning is facilitated through sorting tasks via Wi-Fi. The authors suggested that the AR PDA interface allows players to collaborate more effectively due to the availability of a higher degree of direct manipulation ability over the conventional PC interface.

However, one disadvantage of this game that although individual players can have their own game state views, there is no sense of what other players are doing ("shared group awareness"). Interaction in multi-user environments may thus be impaired with this difficulty in designing such collaborative AR systems [5].

4.3.3 Design for social interaction

Designing for social interaction is one of the applicable areas that can be facilitated by networked handheld AR technologies. It should be emphasized that although the use of social interaction in game design is not unique to handheld AR games, the extent of how they employ social interaction is unique [40]. This is because not only simultaneous interaction between the players (either in the competitive or cooperative mode) in real world tasks can be supported, telepresence-enhancing features are introduced as well.

The following games employ networked or face-to-face communications to promote collaborative / competitive behaviors and interactions. The *Invisible Train* [13] and *The Alchemists* [41]) are multi-player games that game state and information sharing are constantly being synchronized between the players through wireless networking.

BragFish [10] features a combination of social interaction and co-located handheld AR elements within the game. To increase awareness of other players' presence, handheld AR technologies are used to create a shared virtual space in a fishing game that encourages social interaction among the players. Vibrations are triggered when players are reeling the line in and, while a fish is taking the bait. Players are also allowed to 'ram' their own boats into others to steal fishes. Such physical player-actions are intentionally designed to be obvious to allow them to quickly gain situation awareness.

In *Art of defense* [11], players cooperatively defend their bases by the collective moving of tangible objects and pressing buttons (on handheld devices) as game play elements. Co-located players can perceive the physical presence of others and engage in direct social interaction during game play.

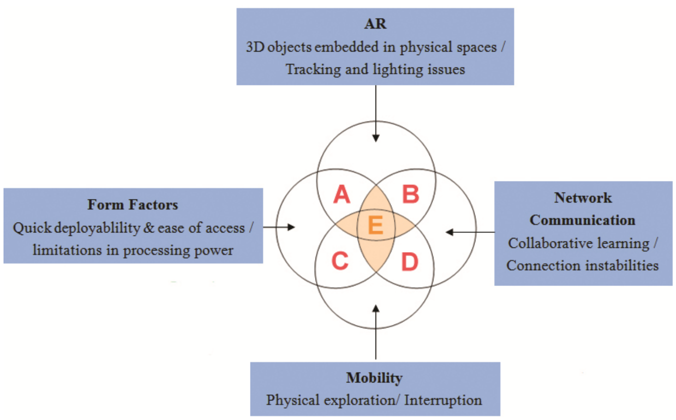
Handheld AR technologies present several unique game design issues. For example, players can use *physical movements* to engage in *co-located* or *remote social interactions* which require effective *interface metaphors* to be implemented into the game design. System performance related uncertainties such as *tracking and communication instabilities* should be designed as integral parts of the game experience. Game design can draw on the characteristics and limitations of handheld AR technologies to construct guidelines.

The next section proposes a design framework for handheld AR games by reviewing several key aspects of handheld AR technologies and the associated game play experiences.

5 Design Framework For Handheld AR Games

Designing handheld AR games require several considerations that go beyond the traditional conventions of the game design process. The game elements that wholly constitute the game mechanics must take into account the three triarchic levels of consideration (Section 2.4) in the design process. These features in the three design levels are not mutually exclusive, although in several of the cases that are brought up in this paper, some of them are taken across the different levels for the purpose of discussion in this study. Notably, these identified elements are not meant to be "should-be-followed" rules, but should be more of a set of applicable considerations to be mindful of, and as design boundaries in the designated technologies that can be offered in handheld AR games.

The design framework consists of a specialized (AR) system level, an application level and an interaction level that arises with the cohesion of dynamics between the system and application levels (Table 1). Design strategies for games are mostly holistic in the sense that although the three levels can influence every aspect of game design, they may conflict when applied altogether in a single game [2]. Relationships that can be established from these three levels thus vary according to the context of the specific application, and the permissible interoperability and applicability. From the handheld AR learning games in our literature review as an example (Section 4.3.2), the nature of learning on the whole comprises of the inter-dependent variables of AR, network communication, mobility and handheld device technological platforms (Figure 1). Learning effects are complemented by the exploitation of several technologies to visualize (learning) content from three-dimensional viewpoints, to support the intuitive manipulation of objects, and to provide better control/guidance during game play (through multi-sensory feedback), etc. This cohesive 'orchestration' as [19] puts it, should also include interventions that are designed to be subtle and not cause disruptions to the game, such as through the use of improved game messages for example.



Interaction	**A** – Overlap between *AR* and *Form Factors*	**Manipulation** – Intuitive use of handheld devices as part of game mechanics
	B – Overlap between *AR* and *Network Communication*	**Feedback** - Multi-sensory feedback / Control of game mechanics
	C - Overlap between *Form Factors* and *Mobility*	**Platform Adoption** - Fits diverse needs of teachers / students
	D - Overlap between *Network Communication* and *Mobility*	**Collaboration** – Mobile social interaction through random encounters with 3rd party(ies)/team member(s)
Application	**E** – Overlapped tri/quad-areas of interplay	**Learning** (as an example), contextual dependent.

Figure 1. Interplay of relationships in handheld AR learning games (C and D are less discussed in reviewed literature).

In a game design, not every known characteristic of featured technologies however may be implemented or adopted, and that any corresponding restriction(s) should not be omitted or ignored when a technology is included [2]. Only a few but essential relationships that are drawn and established from the three respective levels (system, application and interaction) cohesively form an integrated enjoyable game experience. In a definitive statement for this proposed triarchic conceptual design framework, the consideration for handheld AR game design should first be motivated by the specific context-dependent and multi-varied *context, purpose* or *goal* (application level), weighed up with the advantages and limitations of the selected relevant technologies that are required to realize that application (system level), in order to yield both positive and negative affordances to the degree of becoming influential effects on interaction options and seamful measures for designing game mechanics (interaction level).

6 CONCLUSION

This study presents a conceptual design framework for handheld AR games that is derived from the related works, with particular focus on how the reviewed handheld AR games are interlinked in various parts across the three multidisciplinary design levels (system, application and interaction). While many of the related works have paid much relative attention to the introduction and improvement of empowering technologies, handheld AR game design requires a more formalized design framework for better game experiences to be created. From the perspective of interplay between the three levels of consideration, the analysis of reviewed handheld AR games shows how the identified design elements in the interaction level relate the affordances of handheld AR technologies to game experiences, as characterized by the in-built game mechanics. Game designers need to balance between applying conventional game design theories while taking into consideration the characteristics of the technologies and turning them into practical game play advantages and design resources.

Several other interesting works in handheld AR games have been omitted since this study only features those where the actual process of game design manifested. Future work should review each of the mentioned game design features at a more intricate level, explore other possible associations through other projects, and to even attempt to empirically verify the game elements by further user evaluations.

ACKNOWLEDGEMENTS

This research is carried out under NRF project no. WBS R-705-000-025-271 partially funded by a grant from the National Research Foundation administered by the Ministry of Education of Singapore.

REFERENCES

[1] F. Zhou, H.B.-L. Duh and M. Billinghurst, Trends in augmented reality tracking, interaction and display: A review of ten years of ISMAR, *Mixed and Augmented Reality, 2008. ISMAR 2008. 7th IEEE/ACM International Symposium on*, vol., no., pp.193-202, 15-18 Sept. 2008.

[2] M. Montola, J. Stenros and A. Waern. Pervasive Games: Theory and Design. San Francisco, CA, USA: Morgan Kaufmann Publishers Inc.; 2009.

[3] M. Weiser. Creating the invisible interface (invited talk). In: *Proccedings of the 7th annual ACM symposium on user interface software and technologies* (UIST), 1994.

[4] R.T. Azuma. A survey of augmented reality. In: *Presence: Teleoperators and virtual environments*, 6(4):355-385, August 1997.

[5] D. Wagner, D. Schmalstieg and M. Billinghurst. Handheld AR for collaborative edutainment. In: *Proceedings of the 16th international conference on artificial reality and telexistence* (ICAT 2006), p. 85-96, 2006.

[6] H. Kato and M. Billinghurst. Marker tracking and HMD calibration for a video-based augmented reality conferencing system. In: *Proceedings of the 2nd IEEE and ACM international workshop on augmented reality*, p. 85, 1999.

[7] A. Henrysson, M. Billinghurst and M. Ollila. Face to face collaborative AR on mobile phones. In: *Proceedings of the 4th IEEE/ACM international symposium on mixed and augmented reality*, p. 80-89, 2005.

[8] D. Wagner and D. Schmalstieg. ARToolKit on the PocketPC platform. *Augmented Reality Toolkit Workshop*. Washington, DC, USA: IEEE International, p. 14-15, 2003.

[9] D. Wagner. Handheld augmented reality [PHD dissertation]. Styria, Austria: Graz University of Technology, 2007.

[10] Y. Xu, M. Gandy, S. Deen, B. Schrank, K. Spreen and M. Gorbsky. BragFish: exploring physical and social interaction in co-located handheld augmented reality games. In: *Proceedings of the 2008 international conference on advances in computer entertainment technology*. New York, NY, USA: ACM, p. 276-283, 2008.

[11] D.-N.T. Huynh, K. Raveedran, Y. Xu, K. Spreen and B. Macintyre. Art of defense: a collaborative handheld augmented reality board game. In: *Proceedings of the 2009 ACM SIGGRAPH symposium on video games*. New York, NY, USA: ACM, p. 135-142, 2009.

[12] K. Salen and E. Zimmerman. Rules of play: Game design fundamentals. Cambridge, Mass, USA: MIT Press, 2004.

[13] D. Wagner, T. Pintaric, F. Ledermann and D. Schmalstieg. Towards massively multi-user augmented reality on handheld devices. In: *Proceedings of the 3rd international conference on pervasive computing*. Munich, Germany, p. 208-219, 2005.

[14] H. Dixon, V. Mitchell and S. Harker. Mobile phone games: Understanding the user experience. In: *Design and emotion: The experience of everyday things*. London, UK: Taylor and Francis, pp. 256–261, 2004.

[15] B. Bates and R.A. Bates. Game design. 2nd Edition. Boston, MA, United States: Course Technology Press, 2004.

[16] T.W. Malone. Heuristics for designing enjoyable user interfaces: Lessons from computer games. In: *Human factors in computing systems*. New York, NY, USA: ACM Press, p. 63-68, 1981.

[17] Chalmers, M., MacColl, I.: Seamful and Seamless Design in Ubiquitous Computing. Techni-cal Report Equator-03-005, Equator [Technical Reports], 2003.

[18] J.P. Bichard and A. Waern. Pervasive play, immersion and story: designing interference. In: *Proceedings of the 3rd international conference on digital interactive media in entertainment and arts* (DIMEA '08). New York, NY, USA: ACM Press, p. 10-17, 2008.

[19] S. Benford, C. Magerkurth and P. Ljungstrand. Bridging the physical and digital in pervasive gaming. *Communications of the ACM 2005*, 48(3):54-57, 2005.

[20] L. Ermi and F. Mäyrä. Fundamental components of the gameplay experience: Analysing immer-sion. In: *Proceedings of DiGRA 2005 conference: Changing views—Worlds in play. Vancouver: Digital Games Research Association*, 2005.

[21] V. Paelke, C. Reimann and D. Stichling. Foot-based mobile interaction with games. In: *Proceedings of the 2004 ACM SIGCHI international conference on advances in computer entertainment technology*. New York, NY, USA: ACM, p. 321-324, 2004.

[22] A. Park and K. Jung. Flying cake: Augmented game on mobile devices. *Comput. Entertain*. 7(1):1-19, 2009.

[23] A. Park and K. Jung. Augmented galaga on mobile devices. In: *Proceedings of the 2nd international conference on technologies for e-learning and digital entertainment*. Berlin, Heidelberg: Springer-Verlag, p. 888-897, 2007.

[24] E. Barba, Y. Xu, B. Maclntyre and T. Tseng. Lessons from a class on handheld augmented reality game design. In: *Proceedings of the 4th international conference on foundations of digital games*, 2009.

[25] C. Hand. A survey of 3D interaction techniques. *Computer Graphics Forum 1997*, 16(5):269-281, 1997.

[26] A. Henrysson and M. Billinghurst. Using a mobile phone for 6 DOF mesh editing. In: *Proceedings of the 7th ACM SIGCHI New Zealand Chapter's international conference on computer-human interaction*: *design centered HCI.* Vol. 254. New York, NY, USA: ACM, p. 9-16, 2007..

[27] M. Billinghurst, R. Grasset and J. Looser. Designing augmented reality interfaces. *SIGGRAPH Comput. Graph 2005*, 39(1):17-22, 2005..

[28] S. Bucolo, M. Billinghurst and D. Sickinger. User experiences with mobile phone camera game interfaces. In: Proceedings of the 4th international conference on mobile and ubiquitous multimedia. New York, NY, USA: ACM Press; p. 154:87-94, 2005.

[29] L.-H. Chen, C.-J. Yu and S.-C. Hsu. A remote Chinese chess game using mobile phone augmented reality. In: *Proceedings of the 2008 international conference on advances in computer entertainment technologies*. New York, NY, USA: ACM, p. 284-287, 2008.

[30] R.K.C. Koh, H.B.-L. Duh and J. Gu. An integrated design flow in user interface and interaction for enhancing mobile AR gaming experiences. In: *Proceedings of IEEE international symposium on mixed and augmented reality - arts, media, and humanities* (ISMAR-AMH). Washington, DC, USA: IEEE Computer Society, p. 47-52, 2010.

[31] D. Schmalstieg and D. Wagner. Experiences with handheld augmented reality. In: *Proceedings of 6th IEEE and ACM international symposium on mixed and augmented reality*, p. 3-18, 2007.

[32] K. Kuikkaniemi, M. Turpeinen, A. Salovaara, T. Saari, and J. Vuorenmaa. Toolkit for user-created augmented reality games. In: *Proceedings of the 5th international conference on Mobile and ubiquitous multimedia*. New York, NY, USA: ACM, Article 6, 2006.

[33] E. Rosenbaum, E. Klopher, B. Boughner and L. Rosenheck. Engaging students in science controversy through an augmented reality role-playing game. In: *Proceedings of the 8th international conference on computer supported collaborative learning* (CSCL'07). International Society of the Learning Sciences: Clark A. Chinn, Gijsbert Erkens, and Sadhana Puntambekar (Eds.), p. 612-614, 2007.

[34] F.Z. Eishita and K.G. Stanley. THEEMPA: simple AR games using layar. In: *Proceedings of the international academic conference on the future of game design and technology*. New York, NY, USA: ACM, p. 219-222, 2010.

[35] A. Mulloni, D. Wagner and D. Schmalstieg. Mobility and social interaction as core gameplay elements in multi-player augmented reality. In: *Proceedings of the 3rd international conference on digital interactive media in entertainment and arts*. New York, NY, USA: ACM, p. 472-478, 2008.

[36] A. Morrison, A. Oulasvirta, P. Peltonen, S. Lemmela, G. Jacucci and G. Reimayr. Like bees around the hive: a comparative study of a mobile augmented reality map. In: *Proceedings of the 27th international conference on human factors in computing systems*. New York, NY, USA: ACM, p. 1889-1898, 2009.

[37] S.E. Kirkley and J.R. Kirkley. Creating next generation blended learning environments using mixed reality, video games and simulations. *TechTrends: Linking Research and Practice to Improve Learning 2005*, 49(3):42-53, 2005.

[38] K.N. Tran and Z. Huang. Design and implementation of a built-in camera based user interface for mobile games. In: *Proceedings of the 5th international conference on computer graphics and interactive techniques in Australia and Southeast Asia*. New York, NY, USA: ACM, p. 25-31, 2007.

[39] H. Hong, H.Y. Jeong, R.I. Arriaga and G.D. Abowd. TriggerHunter: designing an educational game for families with asthmatic children. In: *Proceedings of the 28th of the international conference extended abstracts on human factors in computing systems*. New York, NY, USA: ACM, p. 3577-3582, 2010.

[40] K. Jegers. Pervasive game flow: Understanding player enjoyment in pervasive gaming. *Comput. Entertain 2007*, 5(1):9, 2007..

[41] W. Broll, I. Lindt, I. Herbst, J. Ohlenburg, A.-K. Braun and R. Wetzel. Toward next-gen mobile AR games. *IEEE Computer Graphics and Applications*, 28(4):40-48, 2008.

A triarchic conceptual framework in handheld augmented reality games

Yu-Ning CHANG
Institute of Communication Studies, National Chiao Tung University, 1001 Ta-Hsueh Rd., Hsinchu 300, Taiwan
aaietw@gmail.com

Raymond Koon Chuan KOH
IDMI /ECE, National University of Singapore, 21 Heng Mui Keng Terrace,I3 Bldg, Singapore 119613
raymondkoh@nus.edu.sg

Henry Been-Lirn DUH
IDMI /ECE, National University of Singapore, 21 Heng Mui Keng Terrace,I3 Bldg, Singapore 119613
eledbl@nus.edu.sg

MobileHCI 2011, Aug 30–Sept 2, 2011, Stockholm, Sweden.
ACM 978-1-4503-0541-9/11/08-09.

Abstract

Rapid development of handheld Augmented Reality (AR) technologies enabled many game implementations on this platform, but prior studies did not draw explicit attention on concepts that exploit or address the inherent relevance of the interdisciplinary domains that may impact game design processes and subsequently gameplay experiences. A triarchic interplay of coherent associations comprising of fundamental system (for pervasive technologies), interaction and application design levels is proposed to allow an informed holistic viewpoint of considerations around the common definitive advantages and limitations that have been identified to be relevant to game design. This framework can be useful as a starting point for an interdisciplinary collaboration to conceptualize and design game experiences for handheld AR games.

Keywords

Handheld augmented reality game, game design, seamful design

ACM Classification Keywords

D.2.10 [Software]: Design—Methodologies.

General Terms

Handheld augmented reality, game, guidelines

Introduction

Advancements in 3D graphics, processor and display technologies invoked a platform evolution for AR-based games on handheld devices which can be described as minimally intrusive, socially acceptable, readily available, highly mobile [10], and are compelling as a platform for pervasive games [7]. Handheld AR-enabled devices enhance gameplay through common digital gaming spaces for players to share social-physical presences with computer vision and/or location (in-situ)-based manipulations. Technology implementations however determine possible game mechanics because of the many ways that virtual information may now be presented in physical spaces using the available traits of hardware (i.e. sensors) and software (i.e. computer vision algorithms) constituents. This affects the interaction options in the design of a handheld AR game, but prior studies mainly advocated technologies and focused less on this inherent relevance.

Related Work

● Handheld AR Games: The use of pervasive devices (i.e. personal digital assistants, mobiles, tablets) with AR technology [1] from year 2000 has opened up new application avenues. It comprises of 4 key constituents, a low-level ***'AR library'***, `***graphics and multimedia support'*** (integrating 2D/3D-rendering with sound engine and/or sensors to establish interaction styles and behaviors), ***'networking'*** (Wi-Fi/Bluetooth, i.e. [4]), and a ***game application architecture***. With the limited computing power in handheld devices, it is always a challenge to sustain gamer-acceptable frame rates for real-time 3D renderings (typical for computer vision based implementations) while tracking is maintained either by fiducial or natural feature-based methods, as both are processor-intensive tasks. Platform optimizations remain as significant research areas as a result. Integrated hardware (i.e. accelerometer, networking support) can introduce multi-sensory/location-based AR experiences in game flows using intuitive mechanisms (i.e. AR and Wi-Fi features exploited as design game mechanics, [9]).

● Game design: Typical approaches usually directly focus on mechanics, interface and game-player interaction, rather than the technological aspects that may affect game experiences [4]. Understanding the affordances of technologies is fundamental to creating a good and novel user experience (i.e. allowing player-sensing and interaction through embedded hardware).

● Seamful design [8]: AR technologies in physical environments exhibit characterized differences called "seams" which can be worked upon to maintain interaction flows between domain constituents, game mechanics and players, while retaining each tool's richness [7]. As an example, mobile access to handheld devices may be non-continuous/limited depending on the environmental factors that devices are used in, this causes player-dropouts or abrupt stops during gameplay. Casual games being easy and short by nature are suitable implementations [2], or mitigation measures [6] can be designed (i.e. automatic game pausing/saving feature for detected breaks).

Three levels of consideration

Game design centered on heterogeneity tends to involve an interdependent underlying *system level* that coherently bears the applied technologies' characteristics. The *system level* supports the intended identified goal(s) in the *application level* (such as for learning), while the *interaction level* is extrapolated from interworking elements of the two levels (system and application) being associated in ascertained compatibility in order to draw consideration and measures. A review of selected games positions distinct attributes of handheld AR technologies into a triarchic consideration (Table 1). When bringing these factors into a game design process, creatively matching supportive appropriations that fulfill an application's primary purpose can help to nullify the various issues and enrich gameplay experiences.

Table 1. Design levels for handheld AR games.

	Goal	**Consideration(s) and measure(s)**
Application	*Learning (example)*	* Exhibit virtual content in physical spaces. * Allow collaborative learning via network communications. * Quick deployablility. * Easily accessible platform. * Induce physical exploration for knowledge inquiry.
	Social Interaction (identified need)	* Enable social communication during game play through: Face-to-face collaborations/competitions (verbal / nonverbal communications), co-located or remote interactions for seamless unity of multiple players. *Instill sense of social and/or physical presence [4].
	Promote use of Contextual Information (identified need)	* Foster explorative mobility of players during game play.
	Attributes	**Consideration(s) and measure(s)**
Interaction	*Manipulation* *Feedback* *Platform adoption* *Collaboration*	* Assert physical affordances of tangible input devices as interaction tools [5] * Enable control of virtual objects by tangible manipulation of physical attributes * Maintain interaction flows * Provide more intuitive and engaging interaction experiences. * Allow progressive task completions * Instill awareness of technological limits via seamful measures.
System	*AR System*	* Use of real-time overlaid 3D virtual objects in the real world * Awareness of game states that are influenced by *slow/inaccurate tracking traits* and *lighting conditions* * Slow tracking: Avoid rapid button presses [9], sudden camera movements and processor-intensive 3D graphics. Technical loads should be balanced (i.e. use pause intervals such as load screens) and pacing should take into account the extent of tracking performance. * Measures for inaccurate tracking: use game rules to visually guide users [3].
	Network communication	* Uncertainties in wireless/co-located communication can employ game structure deliberations ([3]).
	Form Factors	* Design focused activities for small screen displays [7].
	Mobility	* Interruptability: Quickly resume or load the last saved game state. * Gameplay should be short [2]. * Instill contextual adaptability [6].

Results and Discussion

Designing handheld AR games require several considerations that go beyond the traditional conventions of game design processes. Elements that wholly constitute game mechanics and user experiences for handheld AR games can be drawn from the traits of implemented technologies' for its due purpose (application goal). To better approach this continuum of effects that arises during game design, we present a conceptual framework that comprises of an interplay in system, application and interaction design levels. We use the identified need(s) in the application level to determine which system-level components are relevant to establish or propagate interaction opportunities. Using *learning* as the application-level example **(E)**, Figure 1. shows system-level attributes of the framework to establish interaction-level options as represented by the respective dual-overlapped areas, ***Manipulation* (A)***: intuitive use of handheld devices as part of game mechanics.,* ***Feedback* (B)***: multi-sensory feedback of game mechanics.,* ***Platform Adoption* (C)***: fits diverse needs of the intended application.,* ***Collaboration* (D)***: mobile interactions through random or controlled encounters.* This framework maintains that tri-overlapped areas **(E)** represent points of consideration that must address application-level goal(s)/need(s).

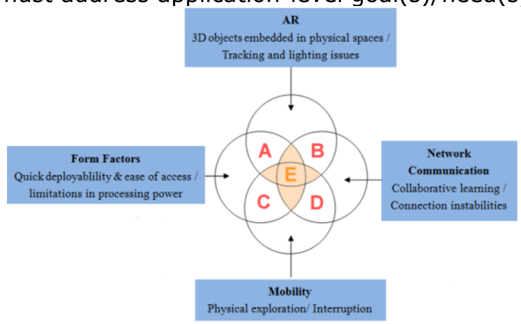


Figure 1. Interplay of relationships in handheld AR learning games (C and D are less discussed in reviewed literature).

Conclusion

Demand for handheld AR games will eventually grow as technologies mature. Their design requires a more formalized framework for considering integrated game experiences. A three-level interplay inculcates how interdisciplinary issues can affect game experiences (mechanics, affordances and interactions), but can be offered as game play advantages and design resources.

Acknowledgements

This research is partially funded by the National Research Foundation through the Ministry of Education of Singapore (NRF Project WBS R-705-000-025-271).

References

[1] Azuma RT. A survey of augmented reality. In: *Presence: Teleoperators and virtual environments 1997*, 6(4), 355-385.

[2] Bates B, Bates RA. *Game design. 2nd Edition*. Boston, MA, United States: Course Technology Press (2004).

[3] Benford S, Magerkurth C, Ljungstrand P. Bridging the physical and digital in pervasive gaming. *Comm. of the ACM 2005*, 48(3), 54-57.

[4] Dixon H, Mitchell V, Harker S. Mobile phone games: Understanding the user experience. In: *Design and emotion: The experience of everyday things*. London, UK: Taylor and Francis (2004), 256–261.

[5] Huynh D-NT, Raveedran K, Xu Y, Spreen K, Macintyre B. Art of defense: a collaborative handheld augmented reality board game. In: *Proc. SIGGRAPH*, ACM (2009), 135-142.

[6] Koh RKC, Duh HB-L, Gu J. An integrated design flow in user interface and interaction for enhancing mobile AR gaming experiences. In: *Proc. ISMAR-AMH*, IEEE Computer Society (2010), 47-52.

[7] Montola M, Stenros J, Waern A. Pervasive Games: Theory and Design. San Francisco, CA, USA, Morgan Kaufmann Publishers Inc., 2009.

[8] Weiser M. Creating the invisible interface (invited talk). In *Proc. 7th UIST*, ACM Press (1994).

[9] Wagner D, Pintaric T, Ledermann F, Schmalstieg D. Towards massively multi-user augmented reality on handheld devices. In: *Proc. of PERVASIVE*, Springer (2005), 208-219.

[10] Zhou F, Duh HBL., Billinghurst M. Trends in augmented reality tracking, interaction and display: A review of ten years of ISMAR. In *Proc. 7th ISMAR*, IEEE Computer Society, (2008), 193-202.