Designing Discoverable Digital Tabletop Menus for Public Settings

by

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A thesis
presented to the University of Waterloo
in fulfillment of the
thesis requirement for the degree of
Master of Applied Science
in
Systems Design Engineering

Waterloo, Ontario, Canada, 2012

AUTHOR'S DECLARATION

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

Ease of use with digital tabletops in public settings is contingent on how well the system invites and guides interaction. The same can be said for the interface design and individual graphical user interface elements of these systems. One such interface element is menus. Prior to a menu being used however, it must first be discovered within the interface. Existing research pertaining to digital tabletop menu design does not address this issue of discovering or opening a menu. This thesis investigates how the interface and interaction of digital tabletops can be designed to encourage menu discoverability in the context of public settings.

A set of menu invocation designs varying on the invocation element and use of animation are proposed. These designs are then evaluated through an observational study at a museum to observe users interactions in a realistic public setting. Findings from this study propose the use of discernible and recognizable interface elements – buttons – supported by the use of animation to attract and guide users as a discoverable menu invocation design. Additionally, findings posit that when engaging with a public digital tabletop display, users transition through exploration and discovery states before becoming competent with the system. Finally, insights from this study point to a set of design recommendations for improving menu discoverability.

Acknowledgements

The completion of this thesis would not have been possible without the support and contributions of many people, to whom all I am so very grateful.

Firstly, thank you to my supervisor, Dr. Stacey Scott, for being the first to even introduce the thought of graduate school to me and encouraging me to do my Master's. I am so thankful for her guidance, support, and supervision throughout the entire process. She helped me develop as a researcher and kept me on track. Thank you also to Dr. Mark Hancock for his expert knowledge and input throughout my research. I would also like to thank Dr. Catherine Burns for being one of my readers and her valuable feedback.

I would also like to extend many thanks to my friends and colleagues in the Collaborative Systems Laboratory. They provided me with support, insight in my research, motivation, and wonderful friendships.

For the development and organization of my study, I owe thanks to many people. Thank you to Dr. Neil Randall for his insight and connecting me with The Museum. Thank you to Robert Post and Justin Lin for their enormous contributions in developing the experimental application. Thank you to Trisha Villanueva for organizing and providing the content used in my study. And thank you to The Museum in Kitchener, Ontario, particularly Lori-Ann Earl, for allowing me conduct my study there and being so accommodating.

I am also thankful to my funding sources for allowing me to focus my time and efforts on my research: Natural Science and Engineering Research Council of Canada (NSERC) and Infusion. I would particularly like to thank my colleagues at Infusion for their valuable insight and knowledge that contributed to my research.

Finally, thank you to my friends and family for your encouragement. Thank you to my friend, Albert for supporting me throughout my time at UW, but most importantly for giving me a good laugh when I needed it most. Mom and Dad, thank you for your unconditional love, support and encouragement. Vicky, thank you for the many encouraging calls; I always felt you cheering me on from afar. And to Aaron, thank you for lovingly supporting me in everything I do; I am blessed to have you by my side.

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List of Acronyms

ANOVA – Analysis of Variance

GUI – Graphical User Interface

M – Mean

PDH – Personal Digital Historian

SD – Standard Deviation

SDG – Single Display Groupware

WIMP – Windows, Icons, Menus, Pointing Device

Chapter 1
Introduction

"All truths are easy to understand once they are discovered; the point is to discover them."

- Galileo Galilei.

The usability of a product or system is defined by its learnability, efficiency, memorability, error rate and satisfaction (Nielsen, 1993). Learnability refers to how quickly a user can become productive with the system. Efficiency refers to how quickly a user can perform the task with minimal errors. Memorability refers to how easily a user can remember how to use the system. Error rate refers to how a user can make and recover from an error. And satisfaction refers to how pleasing a user finds the system to use. All of these factors define the ease of use of a system and are practical for evaluating the use of an interactive system over time. Consider an interactive system in a public setting however. Users in this context are often novice users, walking up and using the system for the first time. They do not have much time to learn and become an expert with the system. Before users can use a system, they must first *discover* it. Discovery is the act of noticing or realizing something. In the context of human-computer interaction and digital interactive systems, a user must first *discover* the entry point of an interface before he or she can use it. This can entail the gross or minute details of a system such as locating the power switch of a desktop computer or discovering the start button of a mobile game.

An interactive system that is growing in popularity in public settings is the digital tabletop. Its large size and multi-touch capabilities invites interaction from multiple users and lends itself to displaying shareable information suitable for public settings. Digital tabletops are increasingly appearing in settings such as corporate or public lobbies, museums, restaurants, and conferences, as depicted in Figure 1.1. Digital tabletops have only recently become commercially available, and therefore many users' first encounters with these systems are in these public settings. High discoverability of the entry point of the system is therefore crucial.

Figure 1.1: Microsoft Surface by Infusion at conferences[1]

A common entry point of interactive systems is through menus. To retrieve information, such as opening an application on a computer, a user looks to the Start menu[2] on a Windows computer or the Dock[3] on an Apple computer. To access functionality, such as saving a file, a user looks to the ‘File’ menu. Although menus are a common graphical user interface (GUI) element, their use on digital tabletops is still relatively new, like the technology itself. The multi-user, horizontal orientation, and touch interaction of digital tabletops present additional challenges to both the user and system designers. A common issue that applies to menus whatever its platform however, is discoverability. In order for users to use a menu, they must first invoke it. To design menus with high discoverability, the menu invocation design must be discoverable.

This thesis examines how menus for digital tabletops in public settings can be designed to be more easily discoverable. More specifically, this thesis examines current digital tabletop menu and menu invocation designs, proposes a new menu invocation design to encourage menu discoverability in public settings, and discusses the development and evaluation of the proposed design.

1.1 Motivation

Two factors motivated the work within this thesis: the necessity of discoverability in the design of digital tabletops for public settings, and the lack of attention in the previous literature to assessing menu invocation and menu discoverability.

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[1] ©Infusion, used with permission
[2] http://windows.microsoft.com
[3] http://apple.com

Many studies have examined the use of interactive displays in public settings (Brignull & Rogers, 2003; Cao et al., 2008; Correia et al., 2010; Hinrichs & Carpendale, 2011; Hornecker, 2008; Jacucci et al., 2010; Peltonen et al., 2008). Findings from these studies highlight the importance of a "walk-up-and-use" system that is self-explanatory to first-time or one-time users so that no prior training is required. In order to achieve such an experience, "immediate apprehendability" (Hornecker, 2008) is required. Users need to experience success early, and quickly discover how to interact with the system (Hornecker, 2008). High discoverability of the system is therefore important to the design of public interactive displays. This includes attracting users to the system and informing them that the system is interactive and usable. Attraction plays an important role in discoverability because in order for users to interact with the system, they must first notice the system and then be enticed to interact with it.

In addition to informing users of the existence of the overall system, discoverability also encompasses discoverability of the system features. This refers to informing users of *how* to use the system such that they understand the purpose of the system. To do so, users need to notice and understand the system's action possibilities (affordances); for example, how to open a menu.

As a first step toward understanding how to design for discoverability of system features in interactive public displays, this thesis focuses on system menus. As a key mechanism for accessing system functionality in many interactive systems, menus have been the focus of considerable research for both traditional desktop computing and digital tabletops (e.g. Callahan et al., 1988; Lepinski et al., 2010). This previous research focused mainly on the design of menu efficiency. In almost all cases, participants in user testing of these menus were explicitly taught the invocation method of the menu and the study measure was efficiency or time of use, rather than invoking the menu. As such, menu invocation has received little attention in the literature and therefore the discoverability of the evaluated menus was not assessed. Prior to menu use, however, we must first ensure the user discovers the menu. To date, little to no research has been conducted focusing on menu discoverability.

1.2 Research Problem

The task of designing digital tabletop menus for public settings faces not only challenges of designing for a digital tabletop interface, but also a need to design for discoverability. Digital tabletops are well suited for use in public settings and present a walk-up-and-use interaction scenario. As most users in this context are first-time users, discoverability plays a key role in achieving ease of use. The discoverability of the system refers to identifying and understanding the use of the system as a whole as well as the system features, such as the individual interface components. A common interface element that is of interest is the menu. Menus are a useful entry point to systems as well as for accessing information and functionality. An unaddressed problem is that in order for menus to be useful on a digital tabletop in a public setting, they must first be designed to be discoverable.

1.3 Research Question and Objectives

The overall research question that is addressed in this thesis is:

How can the interface and interaction of digital tabletops in public settings be designed to encourage menu discoverability?

In order to address the above research question, the research was broken down into the following three research objectives:

- **Determine the existing techniques for designing discoverable tabletop menus.** A literature review was conducted to determine the benefits and limitations of existing menu designs for digital tabletops. This review, presented in Chapter 2, also focused on previous research of digital tabletops and public settings, and menus and menu evaluation research.
- **Design a menu invocation design solution that encourages discoverability on digital tabletops in public settings.** Based on the literature review, a menu and set of menu invocation designs were developed to encourage discoverable interaction. A detailed description of the menu and invocation designs, as well as a discussion of the rationale behind the designs, is presented in Chapter 3.
- **Evaluate the discoverability of the proposed menu invocation designs.** The menu and invocation designs were implemented in an experimental application and evaluated through an observational study in a public setting. The study method is presented in Chapter 4, and the findings and discussion based on the study results are described in Chapters 5 and 6 respectively.

1.4 Thesis Organization

This thesis is organized into seven chapters:

- **Chapter 1, Introduction** – presents the motivation and research objectives of the thesis.
- **Chapter 2, Background** – reviews research literature related to digital tabletop design considerations, interactive public displays, and menu design.
- **Chapter 3, Menu Invocation Design** – describes the design and rationale of a menu and set of menu invocation designs for digital tabletops that encourage discoverability.
- **Chapter 4, Study Method** – describes the design of the observational study used to evaluate an experimental application that demonstrated the various menu invocation designs.
- **Chapter 5, Findings** – presents the qualitative and quantitative results of the observational study.
- **Chapter 6, Discussion** – situates the findings from the observational study in the larger context of designing digital tabletop menus for public settings, presents design recommendations for improving menu discoverability and discusses the limitations of this research.
- **Chapter 7, Conclusions** – discusses how the research objectives were met and presents recommendations for future work.

Chapter 2
Background

This chapter provides an overview of the literature relevant to understanding the domains of interface design for digital tabletops and menu design with respect to the research presented in this thesis. The background presented here is divided into three primary categories of *digital tabletop research, interactive displays in public settings,* and *menu research*. First, an overview of digital tabletop interface design considerations is presented. This is followed by a discussion of large-scale interactive displays in public settings and the challenge of discoverability that these scenarios present. Finally, a discussion of digital tabletops menus and their discoverability is presented.

2.1 Interface Design Challenges of Digital Tabletops

Digital tabletops are large horizontal digital displays that enable multi-touch and/or multi-user interaction with digital information and media. These system qualities introduce several design factors that need to be considered in the design of the user interface and that differ greatly from classic single, desktop computing systems.

2.1.1 Multi-User

The large size and multi-touch interaction of digital tabletops supports multiple users and collaborative work. With multiple users, there are the design challenges of supporting collaboration and simultaneous actions. For a digital tabletop in a public setting, multiple users can comprise users that may or may not know one another. In both cases, the system should not force, but rather it should support collaboration. Gutwin and Greenberg (2000) identified several basic *mechanics of collaboration* that outline actions and interactions that people use to complete a collaborative task. With both collaborative and simultaneous personal interaction on a shared space, there is the need to support simultaneous user actions (Scott et al., 2003). With multiple users, their actions often conflict with one another, both intentionally and accidentally (Ryall et al., 2006). Means to support the mechanics of collaboration and simultaneous actions may be desirable for an effective and usable digital tabletop interface. One proposed method of addressing these challenges is through the use of replicated interface elements (e.g. Morris et al., 2006), as applied in this thesis study.

2.1.2 Single Display

Digital tabletops are a form of Single Display Groupware (Stewart et al., 1999). Its single, shared display presents design challenges such as division of space and organization of content. On shared tabletop workspaces, collaborators tend to divide their space into three types of territories: personal, group, and storage territories (Scott et al., 2004). This observed behavioural tendency translates into the need to support division of space with respect to both functionality locale and item grouping. Despite the natural formation of territories on a digital tabletop, the singularity and size of the display mean that users may easily cross over into others' personal territories. Particularly as the number of simultaneous users increases, crowding and the organization of content poses as a challenge (Ryall et al., 2006). One proposed method of addressing these spatial and organizational challenges is through the use of tangible drawers on the sides of a digital tabletop to store data (Hartmann et al., 2006).

2.1.3 Orientation

The horizontal orientation of a digital tabletop presents the challenges of user arrangement and orientation of content. When multiple users are around a digital tabletop, there are a multitude of possible user arrangements (Inkpen et al., 1999). Particularly in a public setting, users may approach a digital tabletop from almost any direction translating to constantly changing user arrangements. These inconsistent user arrangements result in inconsistent orientations of the data displayed on the digital tabletop. Kruger et al. (2003) found that orientation plays a critical role in how people around tables comprehend information, coordinate their actions, and mediate communication. Proposed methods that can address the challenges of user arrangement and resulting orientation issues include detecting user position to accordingly position interface elements (Hancock & Booth, 2004) and supporting free rotation interactions (Kruger et al., 2003). Another method, applied in this thesis study, is environment-based automatic orientation (Kruger et al., 2004) which orients items based on its location on the digital tabletop (e.g. if an item is opened near an edge of the table, it is automatically oriented assuming the user's vantage point is also from that edge).

2.1.4 Touch Interaction

Although touch interaction is becoming more ubiquitous in everyday life, as an input language, it has not yet become as universal as more traditional mouse interaction (i.e. "point and click") (Wigdor, 2010). Some of the challenges of direct-touch interaction on a digital tabletop are adapting interface elements for touch interaction and teaching users the touch interactions. Interface elements designed for a mouse-input system need to be modified for a finger-based input system (Ryall et al., 2006). With a mouse, the cursor is small and therefore precise pointing is possible. With touch interaction, users can encounter the "fat finger" problem where due to the larger and varying size of users' fingers, they may experience imprecise selection. Touch interfaces therefore need to be designed accordingly to support touch input. A common solution to this challenge is to enlarge the selection/activation area of interface elements (Shen et al., 2006). Particularly in a public setting where many users are novices, a challenge of touch interaction with a digital tabletop is teaching users how to interact with it. A method of addressing this challenge is through the use of self-revealing gestures (Brandl et al., 2008; Wigdor & Wixon, 2011). Self-revealing gestures use proactive feedback to subtly teach specific interactions to users. When a user performs an interaction, other elements of the interface hint to the user's possible subsequent actions.

2.2 Interactive Surfaces in Public Settings

One of the greatest potentials of digital tabletops is its use in public settings. Its large size lends itself to displaying shareable information and invites multiple users and even spectators. Digital tabletop applications are appearing in settings such as museums, restaurants, and schools. A digital tabletop in a public setting presents a walk-up-and-use scenario where users are likely to interact with the system for the first time and additionally may be observed by spectators. Many studies have examined walk-up-and-use scenarios with interactive displays – both wall (vertical) and tabletop (horizontal) displays (Brignull & Rogers, 2003; Cao et al., 2008; Correia et al., 2010; Hinrichs & Carpendale, 2011; Hornecker, 2008; Jacucci et al., 2010; Peltonen et al., 2008). These studies were conducted in a variety of public settings such as universities, aquariums, museums, exhibitions, and city centres, and provide insight on how people interact with public displays.

2.2.1 Interaction Models for Public Displays

Based on multiple studies looking at interactive surfaces in public settings, various models of interaction with large, interactive public displays have been proposed (Brignull & Rogers, 2003; Cheung, 2011; Müller et al., 2010; Vogel & Balakrishnan, 2004). These models outline the states that a user transitions through when interacting with an interactive public display. The models propose that, in general, a user transitions from peripheral, to subtle, to direct awareness or interaction with the system. These different levels of awareness result in different levels of interaction with the system. As an example, the proposed interaction model by Cheung (2011) is shown in Figure 2.1.

Cheung's model describes the "mechanisms and dynamics between human and interactive surfaces in an open setting" (p. 21) with an emphasis on the usability of the interface. It focuses on how the interface of the display leads the user through the different states and how the user initiates the transitions. Furthermore, the model accounts for opportunistic encounters with a public display – where users do not have a specific task or goal in mind when interacting with the displays.

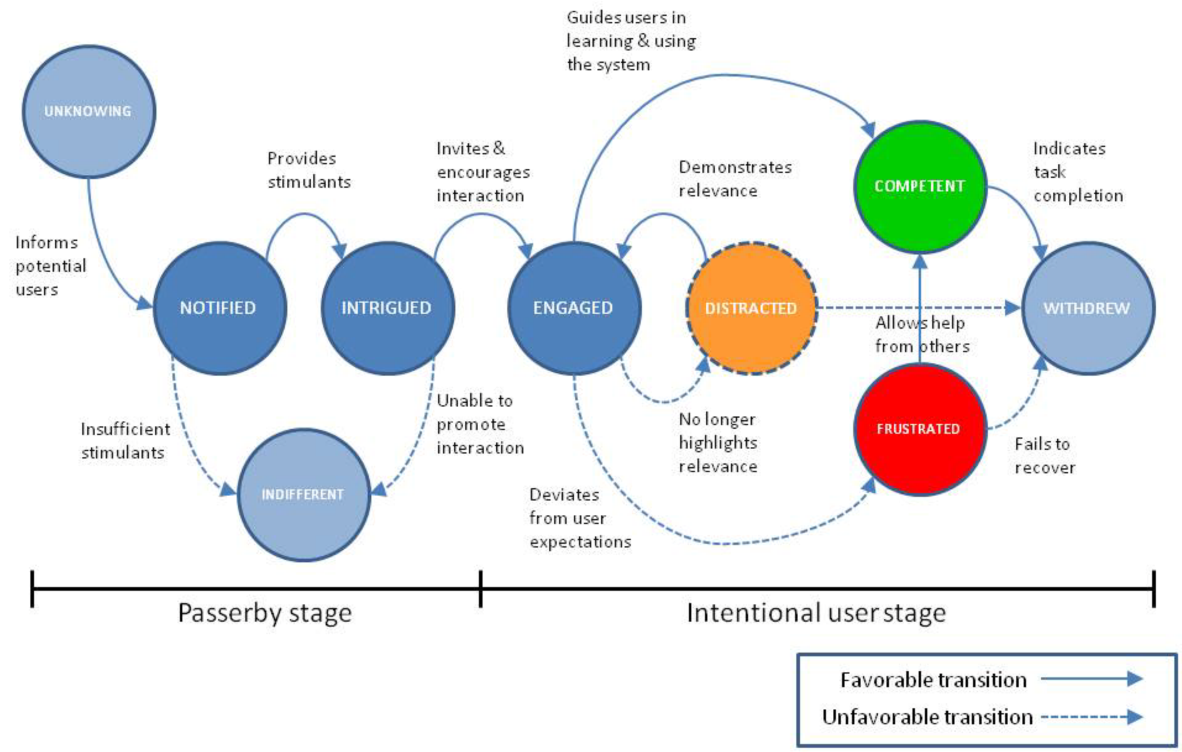


Figure 2.1: Interaction Model by Cheung (2011)[4]

Cheung's model demonstrates the two types of discoverability previously discussed in Section 1.1. The first is overall system discoverability. This is encompassed in the 'Passerby stage', particularly in the transition from the 'Unknowing' to the 'Notified' state. The second type is discoverability of the system features; for example, discovering that the system contains menus. This form of discoverability is captured in the transition from the 'Intrigued' to the 'Engaged' state, and within the 'Engaged' state itself. The user must discover the system features in order to transition to the 'Competent' state. This model is applied to digital tabletops in public settings in the research presented in this thesis with attention to the 'Intrigued' and 'Engaged' states.

[4] ©Victor Cheung, used with permission

In all of the mentioned interaction models, there is focus on the need to capture the user's attention in order for engagement or interaction to occur (e.g. the 'Notified' and 'Intrigued' states of Cheung's model). One method of doing so is through the use of animation.

2.2.2 Animation and Attention

Attention with respect to perception refers to one's allocation of processing resources, ability to focus on a task, and/or ability to concentrate (Wickens & Hollands, 2000). In the context of a digital tabletop in a public setting, it refers to notifying and attracting a user to the system. Animation is an effective means of attracting users to the system because moving or flashing stimuli attracts attention (Bodenhausen & Hugenberg, 2009). Motion is not only highly effective at attracting attention, but also easily perceived in peripheral vision (Palmer, 1999) and can therefore be utilized to attract people that may pass by the public display. Animation can also be emotionally engaging and thus increase levels of engagement (Tversky et al., 2002). Furthermore, animation helps inform users of interface changes (Heer & Robertson, 2007). The inclusion of animation in digital tabletop interfaces may therefore be useful for attracting users to the system, and inviting and assisting user interaction.

2.2.3 Designing for Discovery

Once a public display has caught the attention of a user, the next hurdle is discoverability. Discoverability in this context refers to how easily users recognize the possible actions supported by the digital tabletop system and comprises both the attraction and affordances of the system. In a public setting, users are primarily novice users who are unfamiliar with the system. Furthermore, unlike in a private setting, users are not able to practice nor are explicitly instructed how to use the system. Discoverability is therefore of great importance when designing a digital tabletop system for use in public settings. This challenge is not new and designers offer some general approaches to assist with discoverability.

In many of the previous public display studies, written instructions were posted in proximity of the display to inform users of the purpose of the display and instruct them how to interact with the system (e.g. Cao et al., 2008; Peltonen et al., 2008). This is an explicit method of assisting discoverability. Although, this method provides an unambiguous approach to addressing the challenge of discoverability, Gaver et al. (2003) argue that ambiguity in design can be used to initially draw users into interaction. This mentality is echoed by Agamanolis (2002) who found that ambiguity or mystery can help entice users' natural curiosity and therefore more deeply engage them in interaction. A method that appeals to users' curiosity is through gradual discovery.

Gradual discovery with public displays is encouraged so as to not overwhelm users with instructions or a multitude of unfamiliar interactions (Jacucci et al., 2010). An approach based on gradual discovery is scaffolding. Scaffolding is a method of teaching users how to interact with the system by breaking down larger tasks or challenges into smaller steps to focus on (Wigdor & Wixon, 2011). For example, the interface only reveals a few elements at a time, therefore limiting and guiding what the user can interact with during the exploration process.

Similar to its use with respect to inviting interaction and attention, as discussed in Section 2.2.2, animation can also assist with discoverability. In many of the previous public displays studies, subtle movement of objects were used to inform users that they could manipulate these objects (e.g. Hornecker, 2008). In addition to movement, some studies used the appearance and disappearance of objects to draw attention and invite interaction to these objects (e.g. Hinrichs & Carpendale, 2011; Hornecker, 2008).

Another method of designing for discoverability is through the use of perceived affordances. The notion of an affordance was first introduced by Gibson (1977) as actionable properties between the world and an actor. Norman (2002) later introduced the idea of *perceived affordances* as the possible actions as perceived by the user. Perceived affordances are influenced by the physical capabilities of the user, as well as the user's goals and experiences. With respect to graphical interface design, perceived affordances (or herein referred to as simply 'affordances') are used to communicate to the user what actions are possible. For example, by making a selection element resemble a button, users know that a pushing or tapping action is supported by this element. Affordances can therefore be used to facilitate discovery by highlighting interactive elements of the display.

As highlighted in this section and the previously mentioned interaction models, prior to users being able to engage and use a public display, they must discover how and what can be interacted with on the display. Digital tabletops in public settings bear the same requirement. Many of the aforementioned design methods provide general guidelines to help with discoverability on public displays. These methods can be applied together, for example with self-revealing gestures (Brandl et al., 2008; Wigdor & Wixon, 2011), introduced in Section 2.1.4. Self-revealing gestures employ the scaffolding teaching method through the use of animation and affordances. These methods, along with the challenge and importance of discoverability also apply to individual elements of the interface, such as menus.

2.3 Menus

Designing for touch interaction on digital tabletops often translates to the use of gestures to replace common interface elements such as menus. Although gestures can provide a simplistic feel and appear to take full advantage of the touch capabilities of digital tabletops, they do not have the same advantage of menus. Menus have the advantage of visibility (Norman, 2010); users do not have to memorize or learn complicated commands or gestures as all possible actions and items are easily visible and browsed in a menu. Menus are therefore still useful and indeed used in the design of digital tabletop interfaces.

Since the use of WIMP (Windows, Icons, Menus, Pointing device) interfaces in the 1970's, graphical menus have been a common interface element. The earliest WIMP designs include linear or drop-down menus (Sharp et al., 2007), which are still used today. Since these first designs, much research has gone into various menu designs including flat lists, drop-down, pop-up, contextual, and expanding menus, with the majority of these menus designed for desktop computing. When translating these menus originally designed for desktop use to a digital tabletop, many issues like those outlined in Section 2.1 arise. To address these issues, researchers have developed menus designed specifically for digital tabletop use. These menus address many of the general issues of orientation, multi-user, etc. however do not address the need to design for discoverability; particularly, when a digital tabletop is used in a public setting.

Prior to discussing digital tabletop menu designs, contextual radial menus are introduced because many digital tabletop menu designs stem from this desktop menu design.

2.3.1 Contextual Radial Menus

Radial menus are menus where menu items are positioned along the circumference of a circle at equal distances centered around the cursor. The intention of the design was a contextual, movable menu that minimized necessary hand movement to make a menu selection (Newman & Sproull, 1979). Over the years, the radial menu has evolved into various designs including the pie menu, marking menu, and many variations of the two (Kurtenbach, 2004). Although it was originally designed for use with a mouse, it has been seamlessly adapted for use for touch input (stylus/finger).

A pie menu displays items in a radial layout and uses a gestural style of interaction to make menu selections (Hopkins, 1991). As a contextual menu, pie menus are invoked by clicking or tapping on the item or space of interest. When they appear, the menu is centered around the cursor or input point (point where the stylus or finger was tapped). Displayed menu items are relevant to the selected item or context of use. A selection is made by clicking the mouse (or tapping the stylus) and making a continuous dragging motion in the direction of the selection. Empirical comparisons of pie menus to linear menus found that for single level menus, pie menus were 15% faster and significantly reduced selection error due to the larger target selection areas of pie menus and equal spacing of items from the cursor (Callahan et al., 1988).

From the gestural interaction of pie menus, marking menus were developed. In general, marking menus are an early example of the earlier defined concept of self-revealing gestures (Wigdor & Wixon, 2011). A marking menu functions similarly to pie menus in invocation and selection method, with the primary differences that marking menus' selection paths (or "marks") are based only on directional accuracy (Kurtenbach & Buxton, 1993), and marking leaves an ink-trail after the cursor (Kurtenbach, 1993). Directional accuracy refers to the idea that when making a menu selection, the selection is based on direction of the mark (e.g. north-west) and not on the position or size of the mark. As users become familiar with the marks, they can make selections simply by drawing the desired mark and skipping the step of actually displaying the menu at all. Since the first implementation of marking menus, there have been many variations (Bailly et al., 2007, 2008; Samp & Decker, 2010; Zhao et al., 2006). The primary goals of these variations were to increase menu breadth, improve use/visual search time, and decrease error rates. None of these design modifications however, addressed the issue of informing users how to invoke the menu – discoverability.

Pie and marking menus improve the efficiency of menu use and help users transition from novice to expert users through the use of marks that guide menu selections. No visual indications are used however, to suggest the existence of the menu or how to invoke it.

2.3.2 Adapted Radial Tabletop Menus

The larger selection areas of radial menus make them suitable for digital tabletop use. It is therefore not surprising that many menus designed for digital tabletops use a radial layout.

The X-Menu (Benko et al., 2006) and Occlusion-Aware Menu (Brandl et al., 2009) are examples of radial menus designed for digital tabletops. The X-Menu uses dual finger/hand interaction with the intention of precise selection control. The Occlusion-Aware Menu senses the position of the hand and adaptively displays the menu only in the non-occluded area on the display. Both are invoked like classic contextual radial menus – by tapping the screen and the menu appears centered around the invocation point. Similar to radial menus, these designs offer no visual indications that afford menu invocation.

The Multitouch Marking Menu (Lepinski et al., 2010) is a variation of the classic marking menu. It takes advantage of multi-touch to increase the number of selections available with a marking menu by using directional chording gestures. The menu is invoked by tapping the table with a combination of fingers (a chord); menu items associated with the chord are then displayed circularly and offset so as not to be occluded by the hand. Like classic marking menus, a selection is then made with a directional gesture. Also like classic marking menus, the multi-touch marking menu has no visual cues of how the menu can be invoked. Additionally, although chording gestures widen the breadth of possible menu items, it introduces the need for the user to learn several gestures in order to expertly interact with the menu. This menu is therefore not appropriate for use with novice users in a public setting.

Menus designed for digital tabletops are of course not restricted to radial layouts. User-Drawn Path Menus (Leithinger & Haller, 2007) are a variation on linear menus designed for stylus interaction on a digital tabletop. This design allows users to define the path of the menu as it is invoked. This design is aimed at overcoming the challenge of cluttered tabletop workspaces; however like, the other digital tabletop menus, it does not use visual affordances to indicate menu invocation. The MultiTouch Menu (Bailly et al., 2008) capitalizes on the multi-touch capabilities of digital tabletops and uses chording to make menu selections. A menu is invoked by placing the heel of one's hand on the table and then tapping the screen with a combination of fingers (a chord). Like the Multitouch Marking Menu, this menu design can support many menu items however does not visually indicate its invocation method and requires users to learn complex gestures and chords.

Thus far, many digital tabletop menus have employed the invocation method of contextual menus. These menus can be invoked anywhere on the screen. Looking to desktop computing, we find that users are often trained to invoke functionality or information from the edge of the screen. This is seen in the Taskbar in Windows or the Dock on Apple computers – both situated by default along the bottom of the screen. Within most applications in both platforms, linear menus are accessed along the top of the screen. Extending this "edge-menu-invocation method" to digital tabletops, the edge of the screen can be anywhere along the perimeter due to its horizontal orientation. Two examples of digital tabletop menus that employ this invocation method are the control panels from the Personal Digital Historian (PDH) project (Shen et al., 2003) and the Stacked Half-Pie Menu (Hesselmann et al., 2009).

The PDH uses a circular digital tabletop and features a control panel that can be moved anywhere along the perimeter of the table. The control panel is in essence, an adapted linear menu for digital tabletop use. All buttons are always visible and clearly marked with textual labels, and are therefore always open. This design has high visibility; however the number of items it can support is limited by the number of menus displayed and the perimeter of the table.

The Stacked Half-Pie Menu, shown in Figure 2.2, is a pie menu that is invoked from the edge of a digital tabletop with submenus concentrically stacked on the parent menus. The menu is invoked by tapping on a button at the edge of the table indicating the root layers. A menu selection is made by tapping on the desired menu item. The menu invocation button is always visible and clearly labeled with interaction instructions. This design uses a constant visual element, a button, on the display to indicate the presence and invocation method of the menu and supports a wide breadth and depth of items. As later described in Chapter 3, this menu was adapted for the study conducted in this thesis.

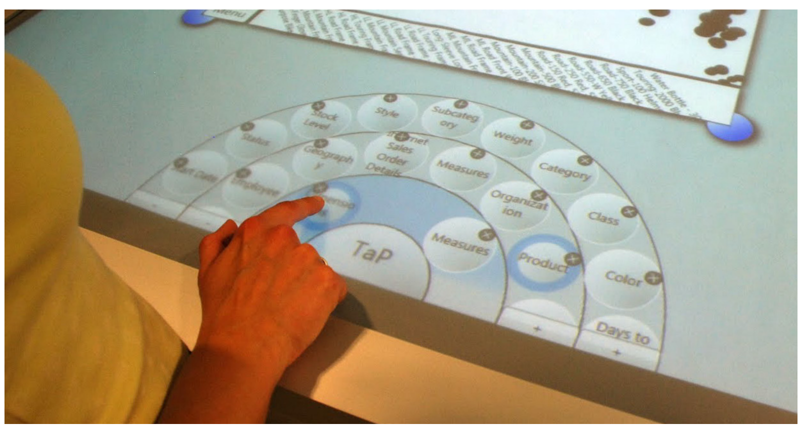


Figure 2.2: Stacked Half-Pie Menu[5]

2.3.3 Menu Evaluations

With all of the aforementioned menu designs, the primary evaluation measure was efficiency. Recruited participants were instructed on the use of or given exploration time with the menus and subsequently evaluated in controlled laboratory studies. Evaluation measures included visual search

[5] ©Tobias Hesselmann, used with permission

time, pointing time, number of errors and frequency based on the Hick-Hyman law (Wickens & Hollands, 2000), Fitts' law (Fitts, 1954) and models such as the one presented by Cockburn et al. (2007). Some studies also evaluated menu usability through standardized questionnaires. The Hick-Hyman law describes human decision time as a function of the information content conveyed by a visual stimulus. Fitts' law describes the movement time taken to acquire, or point to, a visual target. Cockburn et al.'s model predicts menu performance based on these two laws. Menu performance studies evaluated efficiency based on different user scenarios ranging from novice to expert users, and learning over repeated use (repeated-measures study design).

Although controlled studies are effective at assessing menu efficiency, particularly for user trained scenarios, they do not assess *menu discoverability*, which is the focus of this thesis. None of the previously discussed menus were evaluated based on menu invocation. There is therefore evidence of a lack of attention to designing menus for digital tabletops with respect to a discoverable menu invocation experience.

2.4 Chapter Summary

Digital tabletops present a number of interface design challenges. These challenges, coupled with the challenges that a public setting poses, suggest that designing an engaging and usable public digital tabletop display requires careful consideration to the interface elements. One such element is the menu. Many menu designs for digital tabletops have been proposed. The majority of these designs offer solutions to improve menu efficiency or take advantage of touch interaction; however do not propose methods that attract or afford menu invocation. Additionally, most have followed suit with traditional menu assessment methods and focused on evaluating efficiency in laboratory settings. Although controlled studies are effective at assessing menu efficiency, particularly for user trained scenarios, they do not assess menu discoverability, which is important for walk-up-and-use scenarios. Applying the process of menu interaction to the interaction models for public displays presented in Section 2.2.1, a user must first become aware of the existence of a menu and discover how to invoke it. Only then can menu efficiency pertaining to selection time can be considered.

Chapter 3
Menu Invocation Design

This chapter describes the design of the crescent menu and menu invocations evaluated in this thesis. The crescent menu is a half-radial, hierarchical menu designed specifically for direct-touch digital tabletop interaction. It was adapted from the author's previous undergraduate project (Schulze & Seto, 2009). Based on the background literature review presented in the previous chapter, two menu invocation methods were designed: buttons- and border-based invocation methods. With the buttons design, menus are invoked by tapping on a triangular button along any of the four edges of the table. The border design is a modified pie menu tailored to the crescent menu edge invocation constraint. Additionally, a floating images animation was designed as an enticement feature for users, and a pop-up menu animation was designed as an indicative hint to users of where to find the tabletop menus. Both designs varied with the inclusion or omission of these animations. Finally, this chapter presents other design considerations that influenced the final design of the experimental application demonstrating both the crescent menu and the invocation designs.

All menu invocation designs created for this research were designed with the intention to invoke an edge-based menu. Prior to presenting the set of menu invocation designs, the design of the edge-based menu used in this thesis study is first discussed.

3.1 Crescent Menu

In the context of interface design, menu systems are used to organize and present lists of information (or options) to users. The information presented in a menu can vary from a list of commands (functional menu) to a list of documents or artefacts (informative menu). For the scope of this research, the following menu was designed as an informative menu that supports data exploration.

Based on the research presented in Chapter 2 and expanded from the author's undergraduate senior project (Schulze & Seto, 2009), a hierarchical half-radial menu was designed – the crescent menu (depicted in Figure 3.1). This menu was originally designed for an interactive magazine reading application on a direct-touch table as shown in Figure 3.2. It allowed users to browse and preview magazines covers, and subsequently select one for reading, as shown in Figure 3.2. The crescent menu is a radial menu in the shape of a half-moon, hence its name. It is hierarchical in that subsequent levels are stacked on top of the base layer, similar to the Stacked Half-Pie Menu by

Hesselmann et al. (2009). Designed specifically for touch surfaces, it uses large touch areas and supports both gestural and button scrolling. It is designed to invoke from the edge of the surface creating the illusion that items scroll into view from the edge of the table. The full design and functionality of the crescent menu is outlined in Appendix A, with certain design details, particularly those differing from the Sacked Half-Pie Menu, highlighted below.

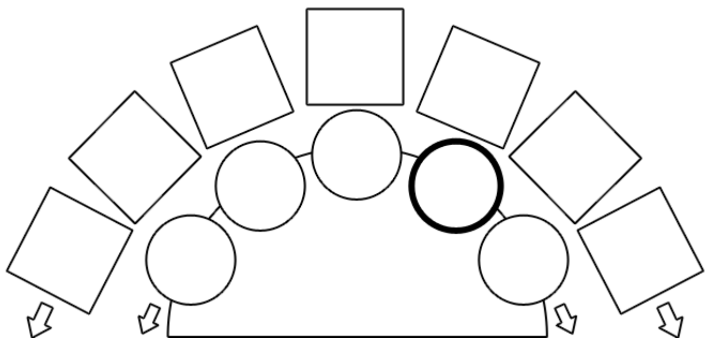


Figure 3.1: Crescent menu

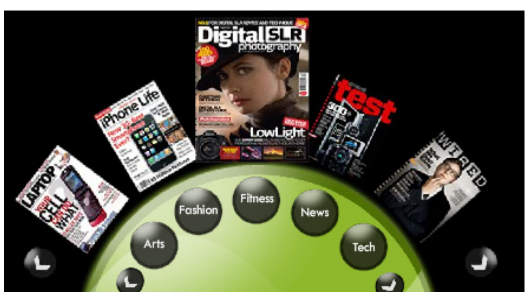


Figure 3.2: Crescent menu for interactive magazine reading application

Figure 3.3: Crescent menu for experimental application

The design of the crescent menu followed a user-centered design approach (Sharp et al., 2007); iterating through paper to digital prototypes whilst incorporating user feedback through each iteration. Specific features that were modified from its original design due to user testing and feedback include the intra-level navigation and the inclusion of transition animations.

Informal user testing conducted during the early design stages of the crescent menu found that users were often confused as to how to view more data within a level. Several button options for intra-level navigation were tested, however arrow buttons were found to be most effective. Furthermore, the direction of scrolling (via arrow buttons) was changed to follow the convention of scrollbars to better match users' expectations. For example, if the user tapped on the right arrow button, the content would rotate to the left to reveal additional content from the right of the menu. In addition to using the arrow buttons to scroll, users can scroll via a dragging motion. This gestural interaction was often undiscovered. To make it more obvious to users, a "shake animation" was added to the menu upon invocation. When the menu first expanded into view, all content would shake slightly - rotating to the right then left slightly. This animation was incorporated with the intention of communicating that the content was scrollable, and that the content was scrollable via a dragging gesture.

Similar to the shake animation, transition animations were added to make users more aware of changes in the menu. When any level of the menu was opened, it expanded into view; and when any level of the menu was closed, it contracted out of view. This was found to be particularly important when users changed swiftly from category to category. The transition animation also provides feedback that touch inputs to change categories were correctly detected.

To close the menu, a slider near the center of the menu is used (shown in Figure 3.3). A user taps and drags the slider into the edge of the table to close the menu. To help make this interaction more discoverable, a down arrow icon is used on the slider button. Additionally, the model of a self-revealing gesture (Brandl et al., 2008; Wigdor & Wixon, 2011) is employed. If a user taps on the slider button, the entire menu will move slightly into the edge. The intention of this animation is to teach users how to close the menu. By continuing with a sliding gesture with the slider, the menu is closed completely. Otherwise, lifting the finger returns the menu to its original position and state.

A feature that was added to the crescent specifically for the context of a public setting is the auto-close functionality. After one minute of inactivity, the outline of the menu glows and the menu slowly slides into the edge of the table. This time-out animation is to notify users that the menu is about to automatically close and gives the user an opportunity to cancel the action by tapping anywhere on the menu. The auto-close functionality was added for public settings, particularly the museum setting in which the observational study (discussed in Chapter 4) was conducted, because it was anticipated that users in this context would likely only spend a brief amount of time interacting with the digital table and not close the menu or any open items. By having the menu automatically close after a designated time of inactivity, this creates a "clean slate" for subsequent users. This was particularly important for the observational study as the focus was on user's initial interactions with discovering the menu.

The final crescent menu developed for the experimental application for this research is shown in Figure 3.3. The following section presents the set of menu invocation techniques designed to invoke this crescent menu.

3.2 Menu Invocation Techniques

To address the research question of menu discoverability, two invocation designs were created: buttons and border. Both methods were designed for and implemented with the crescent menu, and varied with the presence or absence of animation.

All menu invocation designs focused on the use of graphical elements, as opposed to text. This was a deliberate choice for several reasons. Graphical elements, particularly simple shapes, are more orientation-independent than text due to their symmetry. Text can be difficult to read if viewed upside-down or rotated. Furthermore, orientation plays an important role in comprehension in tabletop interaction (Kruger et al., 2003). Particularly in a public setting, where users can potentially approach the table from any direction and are likely novice users, orientation is an important design consideration as comprehension is essential for discoverability. Additionally, graphical elements tend to be more culturally diverse as there are no language barriers. Text needs to be translated for different languages, whereas graphics or icons for the majority do not (for example, the 'Print' icon in Figure 3.4).

Figure 3.4: Print icon

Lastly, graphical or iconic designs are more compact and can be more variably positioned on a display compared to text (Sharp et al., 2007). Although the large size of digital tabletops translates to a large display area, its large size and multi-touch interaction also invites multiple users. With multiple users on a digital tabletop, personal and shared spaces need to be considered (Scott et al., 2004) and interface elements need to be designed accordingly. As such, the division of space and consideration of placement of interface elements is perhaps more important to consider than with traditional single user computing systems.

3.2.1 Buttons

Buttons are a common interface control element found on digital displays regardless of the medium. Based on the physical button design, for example elevator buttons, buttons afford pushing or tapping. They are used with current menu designs such as drop-down menus. The first invocation design is therefore based on these tried and tested interface elements – buttons. This invocation design, shown in Figure 3.5**Error! Reference source not found.**, allows users to invoke a menu by tapping on triangular-shaped buttons situated along the interactive edge of the digital tabletop. A menu then opens in place of the button. The placement and quantity of the buttons can vary depending on the size of the digital table. The button invocation design helps to mitigate the chance of overlapping menus as well as it clearly communicates the number of menus the digital tabletop can support. Because the buttons are fixed, they can be appropriately distanced from one another so as to mark a user's personal space. The quantity of buttons displayed indicates the number of menus that the digital tabletop can support.

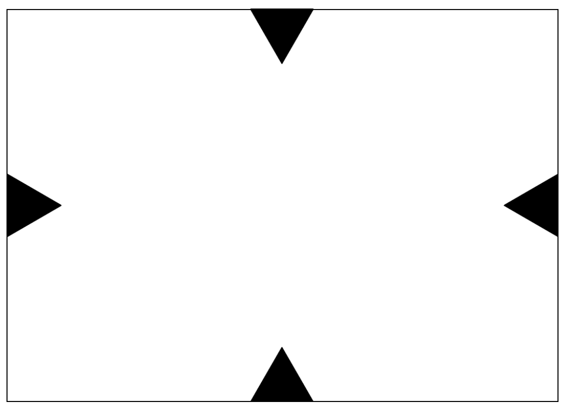


Figure 3.5: Buttons invocation design wireframe

The triangular shape of the buttons was chosen as it bluntly protrudes from the interactive edge of the digital tabletop and is therefore an obvious visual element on the display. The flat black colouring of the buttons was chosen so as not to introduce any confounding factors, such as colour and beveling effects, to the observational study discussed in the next chapter. Additionally, some styling effects, such as beveling a button to make it appear as though it is raised, can be misleading if viewed from an alternative orientation (Scott, 2005). For example, Figure 3.6 shows a beveled button viewed right-side-up and upside-down. In the upside-down view, the button appears to be depressed instead of being raised, as was the intention. The display of a digital tabletop is horizontal and therefore presents orientation challenges as users can approach the system from any side.

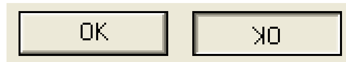


Figure 3.6: A beveled button viewed in two orientations (from Scott, 2005) [6]

To attract the user's attention to the buttons and indicate its interactivity, a glow effect was applied to each button. A pulsating blue gradient animation emanating from each button, shown in Figure 3.7, was used. The glow effect was designed so as to draw new users' attention to them but not be too distracting to users already interacting with the digital tabletop.

Figure 3.7: Buttons invocation design in experimental application

3.2.2 Border

The border invocation design is based on the pie menu invocation method. Pie menus are a form of pop-up menu, invoked only upon need, and typically have the flexibility to be invoked anywhere on the screen. Applying this to the crescent menu specifically, which can only be invoked along the edge of the table, the invocation area needs to be restricted. The border design, shown in Figure 3.8, allows users to invoke a menu anywhere along the interactive edge of the digital table by tapping on the demarcated border, which indicates the invocation area. A menu then opens at the location at which it was invoked. This design gives users flexibility in the menu placement.

Menu placement is particularly important to consider for shared tabletop and public settings – as investigated here. Digital tabletops invite shared and collaborative interaction, and thus simultaneous users. A digital tabletop in a public setting may therefore invite several users at a time who may not know one another. Scott et al.'s (2004) research on table territoriality found that people naturally form

[6] ©Stacey Scott, used with permission

personal workspaces when working on tables in groups. To support this behaviour and social convention of personal space, particularly with strangers, the border menu design provides flexible menu positions. With this design, users can approach the table from any direction and can adjust their menu invocation position for a comfortable personal workspace.

To indicate that the border is interactive, the same glow effect (to that of the buttons design) was implemented on the border (see Figure 3.9). Similar to the buttons design, the purposes of the glow are to draw the users' attention to the border and to invite interaction. When no menus are open, all border edges display the glow effect – a pulsating blue gradient effect emanating from the border. When an edge has reached it maximum capacity of open menus, the glow effect is no longer displayed on that specific edge. The glow effect therefore has the added purpose of indicating to users which edges of the table can support additional users. To increase the hit area of the border, tapping on the glow effect of the border also invokes a menu.

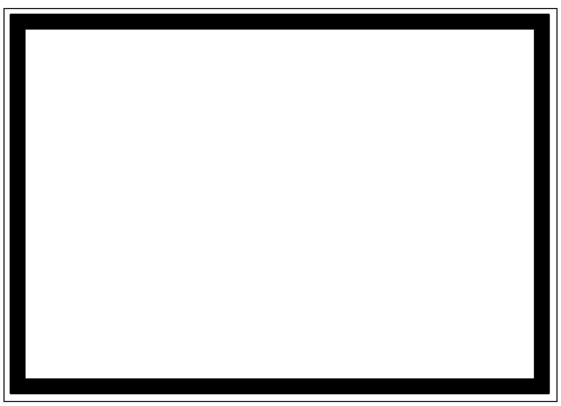


Figure 3.8: Border invocation design wireframe

Figure 3.9: Border invocation design in experimental application

3.2.3 Animation

In public settings, there are often various stimuli competing for one's attention (Müller et al., 2010). An effective means of attracting attention is through the use of animation. The sudden appearance of moving and/or luminous objects appeals to one's behavioural sense that this stimuli may be urgent information and therefore attracts attention (Bodenhausen & Hugenberg, 2009). Based on these reasons, animation was paired with the two invocation designs (buttons and border) to attract users to the table and direct their attention to the appropriate invocation elements. To achieve these goals, two animations were designed and implemented.

The first animation, depicted in Figure 3.10, is floating images that spawn from the center of the table, enlarge as if rising, and then randomly drift into the interactive edges of the digital tabletop. This animation is played when the digital tabletop is in its "attract" mode – no users are interacting with the system and no content is open. This animation serves multiple purposes. First, the floating images are intended to attract users to the table and to invite interactivity. Second, the floating images are translucent samples of the content that can be found in the crescent menu if invoked and therefore hint to the user what information is stored on the system. Third, the images drift into the edges of the digital tabletop with the intention that they direct users to the location at which to find this information, and subsequently how and where to invoke a menu. The floating images are non-interactive. This was a deliberate design decision with respect to the study as interactive floating images may have detracted users from discovering the menu and therefore affected the study results. To help communicate to users that the floating images were non-interactive they were made translucent.

The second animation was a result of the pilot studies (discussed in Chapter 4). During the pilot studies, it was observed that participants had difficulty finding the menu in any of the menu invocation conditions. To address this issue, a pop-up animation was added. When the digital tabletop is in the attract state and a user taps anywhere on the screen (other than the invocation elements), a pop-up of a partial menu jumps quickly out and then back in from the edge of the table at the location of an invocation element (as shown in Figure 3.11). The design of this animation was based on a self-revealing gesture to help teach users how to invoke a menu. The intention of adding the pop-up animation was to hint to the users the presence of a menu in the edge of the table as well as direct their attention to the location at which to invoke/find it. The swift timing and movement of the animation is based on the previously presented research that motion is effective at attracting attention, particularly if in the user's peripheral view (Palmer, 1999).

Figure 3.10: Floating images animation

Figure 3.11: Pop-up menu animation

3.3 Other Design Considerations

During the pilot studies, it was observed that several participants tended to first tap in the center of the table, regardless of the invocation design or presence of animation. It was believed that this was influenced by the circular text in the center of the application's background image as shown in Figure 3.12. A possible reason for this behaviour trend is that the circular text outlined a shape that may have appeared to be a button to some users. To try to eliminate the background as a confounding factor to the study, it was changed to two parallel lines of lighter text as shown in Figure 3.13.

Figure 3.12: Application background with circular text

Figure 3.13: Application background with linear text

Chapter 4
Study Method

This chapter describes the study method used to evaluate the crescent menu and menu invocation designs described in Chapter 3. As the goal of the study was to compare the discoverability of the different menu invocations designs as well as assess the usability of the overall menu design, it was important to design the study such that it would closely resemble a realistic walk-up-and-use situation in a public setting. An observational study in a museum was conducted. An observational study was selected as it is a non-intrusive yet information rich method of watching users in as natural as possible a way. The museum setting was chosen as there is typically a constant flow of people through the space, and museum visitors expect to interact with exhibits in a public space, therefore making it an appropriate choice.

The two menu invocation designs, with and without animation, were showcased through a media browsing application displayed on a SMART Table[7] for a period of four days. Museum visitors were free to interact with the digital table as they pleased and data were collected by field notes, computer logs, and video recording. A combination of qualitative and quantitative analysis techniques were used to analyze the study data.

4.1 Study Design

As the goal of this thesis research is to improve discoverability of interfaces for the general public, it was necessary to conduct the study in a realistic setting. Secondly, to investigate discoverability on a digital tabletop, it was necessary to allows users to unobtrusively interact with the system. Based on these criteria, an observational study was selected. McGrath's Research Strategies Circumplex, depicted in Figure 4.1, classifies various research strategies in relation to one another and three primary study factors: precision, generalizability, and realism. In this circumplex, the study method selected for this thesis research falls under the category of 'Field Experiment' (see highlighted sector in Figure 4.1.). Field experiments are studies conducted in a realistic setting (i.e. in the field) with the deliberate manipulation and control of some feature whose effects are to be studied (McGrath, 1984). Similar studies in the field of human-computer interaction have employed this methodology to study

[7] http://smarttech.com

multiple designs in a field setting (Galegher & Kraut, 1990; Morris et al., 2008). In this thesis research, the controlled features were the menu invocation designs.

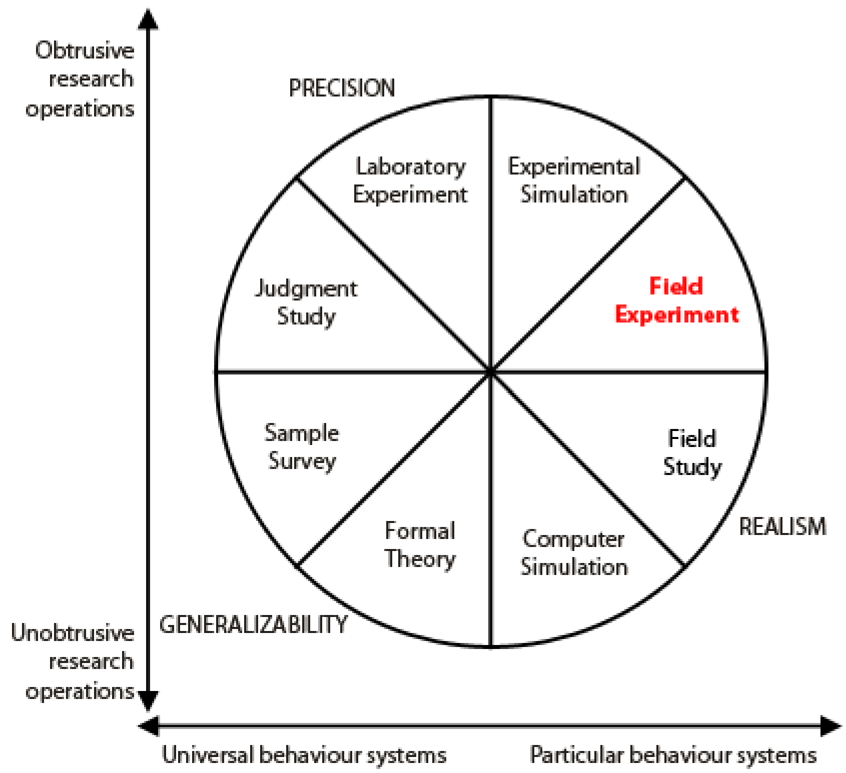


Figure 4.1: Research Strategies Circumplex (adapted from Figure 3-1 of McGrath, 1984)

A 2x2 factorial design observational study was conducted to observe the difference in menu invocations. Two independent between-subject variables were used: the invocation type (border vs. buttons) and animation (animation vs. no animation). Together they formed four different menu invocation designs. The independent variables are outlined in the following two sub-sections.

4.1.1 Invocation Types

The invocation type specifies the interface element from which the menu is invoked. For the following study, two invocation types described in Section 3.2, border and buttons, were used.

Both invocation designs invoked the crescent menu described in Section 3.1. For the scope of this thesis, the implemented crescent menu used a depth of two. Furthermore, due to the size of the SMART Table, both invocation designs only allowed one menu to be invoked per edge at a time, for a maximum of four menus opened at a time.

4.1.2 Animation

As described in Section 3.2.3, animation was defined to have two components: the floating images attraction animation as well as the pop-up menu hint animation. The menu invocation designs *with* animation displayed both of the animation components and those *without* animation displayed none. Figure 4.2 and Figure 4.3 depict each invocation type with animation.

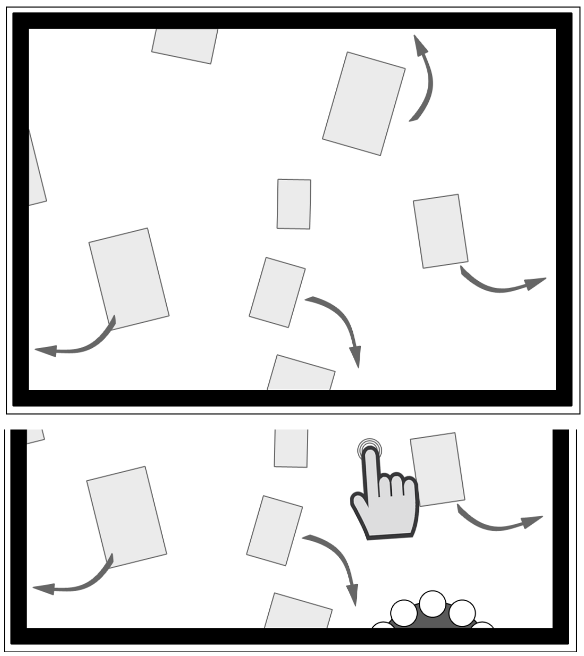


Figure 4.2: Border invocation with animation

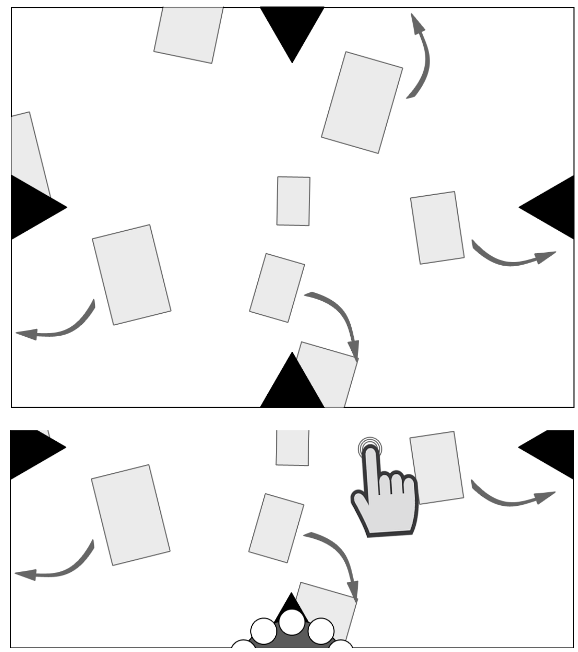


Figure 4.3: Buttons invocation with animation

4.1.3 Study Conditions

Combining the two variable designs – invocation type and animation – the following four conditions were used in the observational study:

1. Border + Animation
2. Buttons + Animation
3. Border (without animation)
4. Buttons (without animation)

4.1.4 Study Schedule

The visitor traffic at the museum varied during different times of the day. To ensure that all four menu invocation designs were shown equally, the four conditions were counterbalanced using a Latin Square across the four days of observation. The study schedule is shown in Table 4.1. In order to avoid disrupting participants' interactions, the breaks between conditions were chosen based on logical breaks in the flow of museum traffic and were determined by the experimenter. On average, each condition was shown for 80 minutes per day.

Table 4.1: Study Schedule

	Day 1	Day 2	Day 3	Day 4
Time 1	Border + Animation *(80 minutes)*	Buttons + Animation *(81 minutes)*	Border *(75 minutes)*	Buttons *(83 minutes)*
Time 2	Buttons + Animation *(75 minutes)*	Border *(79 minutes)*	Buttons *(78 minutes)*	Border + Animation *(78 minutes)*
Time 3	Border *(79 minutes)*	Buttons *(77 minutes)*	Border + Animation *(96 minutes)*	Buttons + Animation *(75 minutes)*
Time 4	Buttons *(81 minutes)*	Border + Animation *(75 minutes)*	Buttons + Animation *(81 minutes)*	Border *(85 minutes)*

4.2 Participants

Each day, observations were taken for a five hour period from approximately 10 AM to 3 PM. Over the course of the four-day observational period, 226 groups interacted with the SMART Table. Interaction times ranged from one second (i.e. a passing tap) to 20 minutes (i.e. opening and interacting with several menus and items from the menu). Museum visitors appeared primarily to be children aged 4 to 12, adolescents aged 13-18, and adults aged 25 to 75, including males and females of varying ethnic backgrounds. Visitors interacted with the table as individuals, and groups ranging from 2 to 8 people. Each visitor group typically consisted of one adult plus multiple children, with the exception of kids' camp and daycare groups. In these cases, groups of only children were in the majority. Figure 4.4 shows the different user configurations of visitors that interacted with the digital tabletop. All age classifications are of the judgment of the researcher as no personal information was collected from the participants.

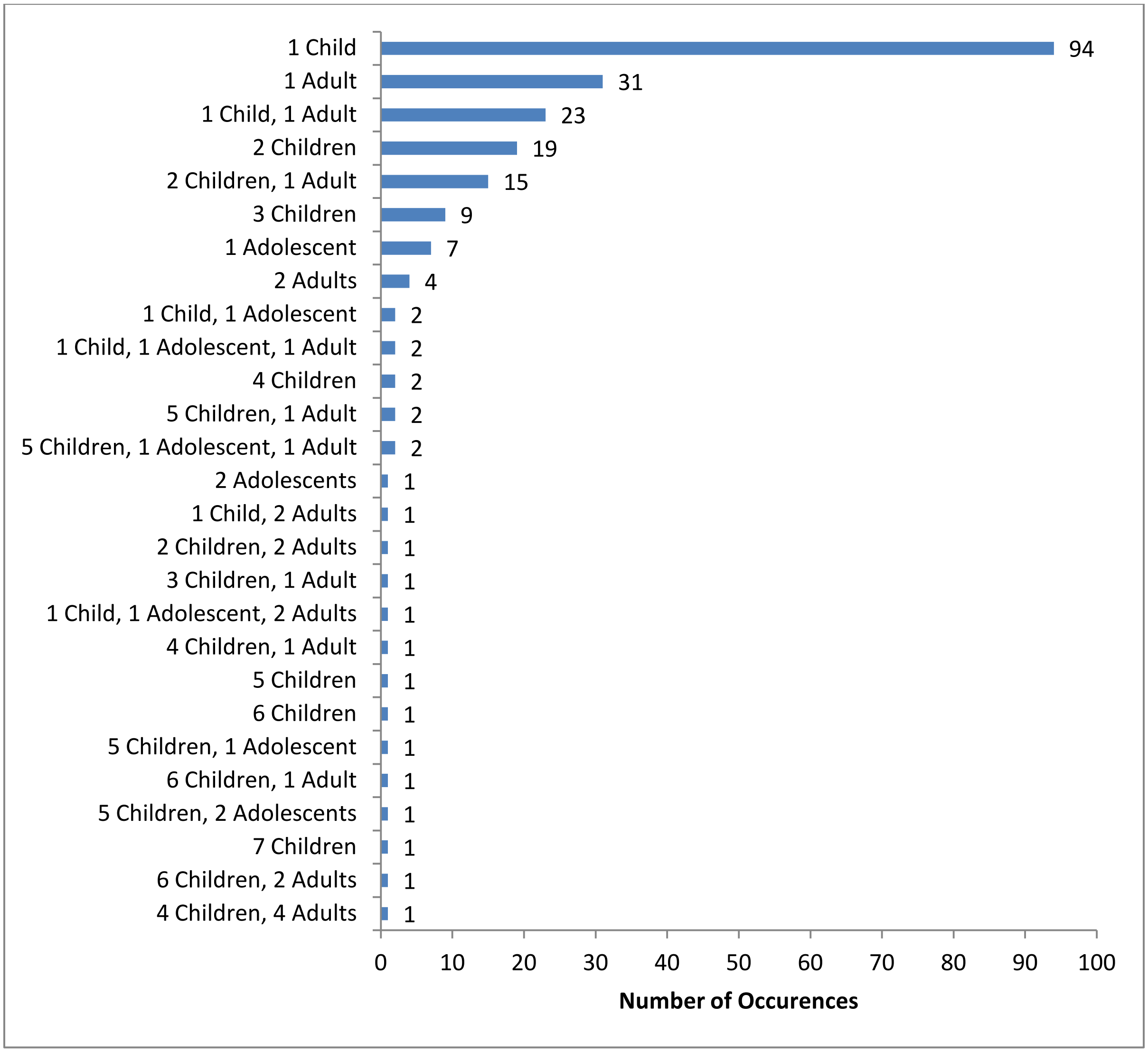


Figure 4.4: Participant Group Configurations

4.3 Equipment and Setting

The study took place at THEMUSEUM in Kitchener, Ontario from August 23rd to 26th of 2011. THEMUSEUM is a local museum originally catered to children, but has recently branched out to include exhibits for a broader audience, such as The Titanic and Tom Thomson. THEMUSEUM consists of four stories with floors 1 through 3 dedicated primarily to children. The fourth floor is typically dedicated to their featured exhibit. At the time of the study, the featured exhibit was "Animal Grossology".

An observational area and the experimental equipment were set-up on the second floor of the museum. Surrounding exhibits included a bed of nails, a water table, craft station, motion activated television, do-it-yourself fabric maze, pin wall, and other exhibits primarily geared towards children. Directly across from the observational area was a motion activated wall. Within the observational area, a SMART Table was set-up to run the experimental application (described below). This table provides a kid-friendly form factor (91.5 cm × 74 cm × 65.4 cm) that was appropriate for the anticipated participant population, and all physical and technical components of the digital table were securely encased within the table itself making it robust for public display. The SMART Table had a 71.5 cm (diagonal) interactive touch screen with 1024x768 display resolution. The observational area also contained two small tables with two to three chairs situated approximately 2.5 meters away on either side of the SMART Table. The researcher sat at one of these tables recording field notes by hand. A picture and overhead layout sketch of the observational area are provided in Figure 4.5.

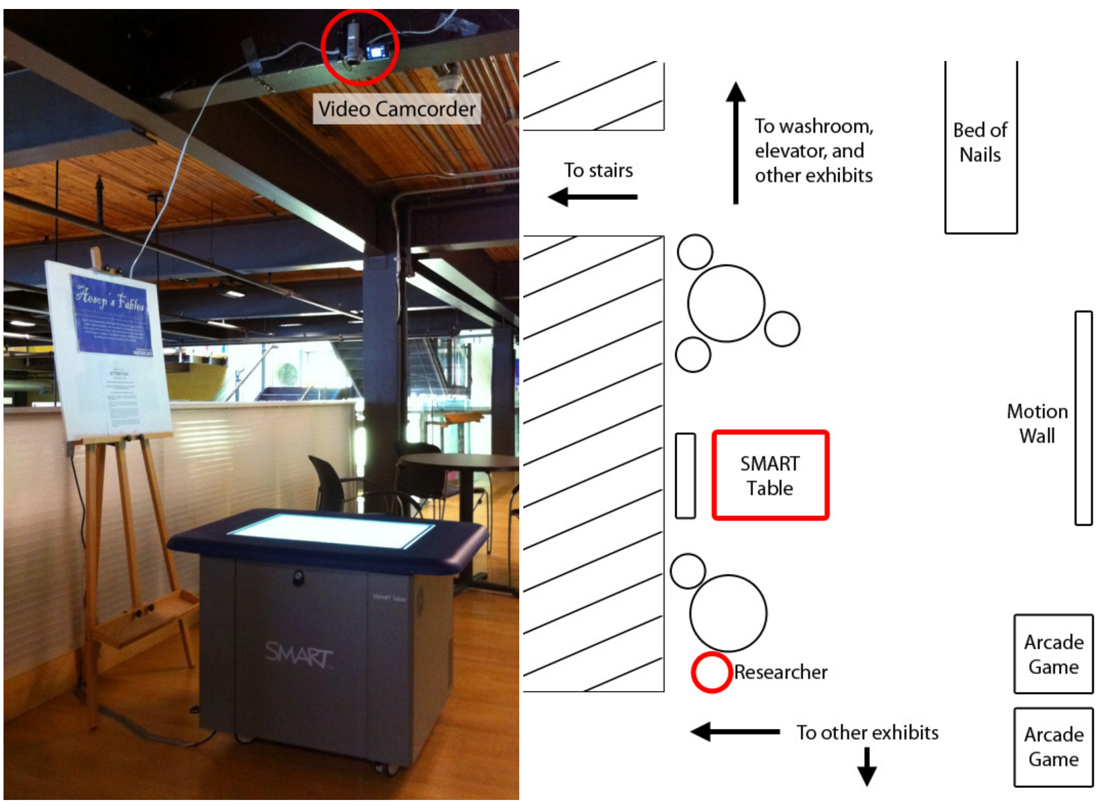


Figure 4.5: Study Set-Up (diagram on right is not to scale)

4.4 Experimental Application

To demonstrate the four study conditions, a media browsing application was developed for an interactive digital table. The application allows up to four crescent menus to be opened (one on each edge of the table), each activating the identical collection of videos and images. Based on findings from Morris et al.'s (2006) previous research on replicated (multiple) versus centralized (one) menus, replicated menus were chosen in this application. Their research found that replicated menus support multiple users while reducing the discomfort and aversion of co-touching. Particularly in a museum setting, these are important factors to account for as users may not know one another. The media browsing application always displayed information using the crescent menu; however the invocation design was interchangeable. This ensured that all four study conditions could be tested.

The media browsing application featured several images and videos all created by the University of Waterloo Digital Arts Communication 400 class (Spring 2011 term). All content was animated interpretations of various fables by the author Aesop (e.g. The Tortoise and the Hare). This content was selected for the study as it was appropriate for a wide range of audience (particularly children) and could be displayed as a stand-alone exhibit in a museum. The hierarchical organization of the crescent menu was leveraged to organize the content such that level 1 displayed the various fables, and level 2 displayed content pertaining to the selected fable. Text was avoided when possible for both the menu and the images to minimize orientation and display (resolution) issues. A screenshot of the final application is shown in Figure 4.6.

The experimental application was developed in Microsoft Visual Studio 2010 using C# and XAML, and implemented for version 2 of the SMART Table.

Figure 4.6: Media browsing application screenshot

4.5 Procedure

Museum visitors were not instructed as to what task to complete on the digital table or how to interact with it. Since the goal of the study was to assess the discoverability of the menu designs in as realistic as possible manner, museum visitors were never verbally approached to ask to participate. Although participants were never informed of any particular order of interaction with the SMART Table, a typical interaction consisted of the following events:

1. Noticing the SMART Table
2. Approaching the SMART Table
3. Interacting with the interactive (touch sensitive) area of the table
4. Opening a crescent menu
5. Navigating through the menu
6. Selecting an item from the menu to open
7. Manipulating the open item (rotate, translate, resize, and/or move)

As outlined in more detail in the following chapter, the length of each event and the number of events completed varied across participants. Participants were free to interact with the table for as short or long a period as desired.

To help maintain the realism of a museum exhibit, a non-intrusive method of participant consent was used. A large sign posted directly behind the table informed museum visitors that by interacting with the SMART Table, they were implicitly giving consent to be observed and video recorded. As well, the sign informed visitors that additional information about the study was available from the on-site researcher. Since neither personal information nor intentional video recordings of faces was collected, the participation of children was allowed. Additionally, a sign explaining the content on the SMART Table and accrediting the university class that created it was posted with the consent signage. This explanatory sign also helped to tie in the SMART Table to the other museum exhibits on the floor as each exhibit had a coloured sign with a title and explanation of the exhibit. The signage and related study material are included in Appendix B.

4.6 Data Collection

Three forms of data collection were used: field notes, computer logs, and video recording. First, the researcher recorded field notes by hand while seated at a nearby table. Observations focused on whether or not the group noticed the table, attempted to interact with the table, successfully opened one or more menus, general details about their interaction with the table, and age group of the users. Second, the application on the table automatically captured users' interaction to a computer log – recording each touch point on the screen. Detailed information on the time, location (exact coordinates and element), and the event (specific action, e.g. menu open) were recorded. Finally, a video camcorder was affixed directly above the digital table to capture a bird's eye view of the table and any interactions (see Figure 4.5). The camcorder recorded both video and audio. The video footage acted as a means to better understand the computer log files, as well as to capture any important observations that the researcher may have missed in the field notes. The video capture area extended approximately 0.5 m from the length of each side of the table (as shown in Figure 4.7). This was useful in viewing if participants approached the digital table but did not interact with it.

Figure 4.7: Video recording samples with (left) and without participants (right) present

4.7 Data Analysis

Users tended to interact with the digital tabletop in groups; therefore all analysis was conducted treating each group as one unit. Furthermore, as the focus of the study was discoverability, it was assumed that each individual in a group may be influenced by learning effects as a result from seeing other group members' interactions. The criterion used to differentiate groups was that there was no overlap in time between interacters from one group to the next. All members of a group were exclusive of the previous or immediately following groups (adjacent groups).

The study data were analyzed using a combination of qualitative and quantitative methods. To validate the collected data, the video, log, and field data were amalgamated, verified against one another, and then sorted based on user groups and study condition. This was conducted in conjunction with a multi-pass strategy for the video data and an open coding (Corbin & Strauss, 2008) approach to note behaviour trends. Table 4.2 outlines a summary of the main codes applied in the data analysis. The full coding scheme including code definitions can be found in Appendix C. The video data revealed interactions that would not have been possible to detect solely from the log files or field notes and provided a more thorough understanding of the overall data.

Table 4.2: Coding Scheme

Category (High-level code)	Code (Low-level code)	Source
User Demographic	Adult	Field notes, Video
	Adolescent	Field notes, Video
	Child	Field notes, Video
Initial Interaction States	Notice	Field notes
	Approach	Field notes, Video
	Interact	Field notes, Video, Log files
Table Start State	Previous menu(s) open	Field notes, Video, Log files
	Previous content open	Field notes, Video, Log files
Exploratory Interaction	1st touch on floating images	Video
	1st touch on open space	Video
	1st touch on invocation element	Video, Log files
	Interact with pop-up	Field notes, Video
	Interact with floating images	Field notes, Video
Menu Invocation	Invoke menu at pop-up	Field notes, Video, Log files
	Intentional menu invocation	Field notes, Video, Log files
	Unintentional menu invocation	Field notes, Video, Log files
General Interaction	Technical error	Field notes, Video, Log files
	Try to control motion wall	Field notes, Video

Statistical tests were conducted on the quantitative data obtained from the data coding, for example, number of menus invoked per condition. These tests included independent sample t-tests and two-way analysis of variances (ANOVA). Each condition experienced different numbers of groups across the 4-day study period due to the varying visitor traffic at the museum. To account for these differing sample sizes, the mean for each condition per day was calculated and analyzed as one sample, thereby obtaining four samples per condition (one for each day). This data treatment was used for all statistical calculations. The findings of this analysis are presented in subsequent Chapters 5 and 6. Full details of any statistical tests conducted can be found in Appendix D.

Although all user groups were initially analyzed, only those who interacted with a clear table – no open menus or items on approach to the digital tabletop - are discussed in subsequent chapters. The data analysis includes 187 groups that interacted with a clear table of the total 226 groups. In order to study menu invocation, it was important to focus the analysis on the invocation elements. Open content on the table may have provided additional visual indications of the presence of data and the menu on the tabletop, therefore biasing the interactions of some groups. Additionally, open content on the table presented distracting factors that influenced users' behaviour differently than those who first interacted with a clear table. A clear table was important for data analysis because it provided a consistent starting state for all groups. The quantity, organization, and size of open content were uncontrolled factors.

4.8 Chapter Summary

A 2x2 factorial observational study was used to evaluate and compare the four menu invocation designs. These four study conditions were demonstrated in a media browsing application implemented on a SMART Table, and displayed at a museum. Participants were unobtrusively observed over a four-day period. The collected field notes, computer logs, and video recordings were analyzed using a mixed method of qualitative and quantitative techniques. The results from this study are presented in the following chapter.

Chapter 5
Findings

Based on the data analysis described in Section 4.7, Cheung's (2011) interaction model for surfaces in public contexts was refined as shown in Figure 5.1. The model outlines the states that participants transitioned through during the observational study and shape the findings presented in this chapter. .

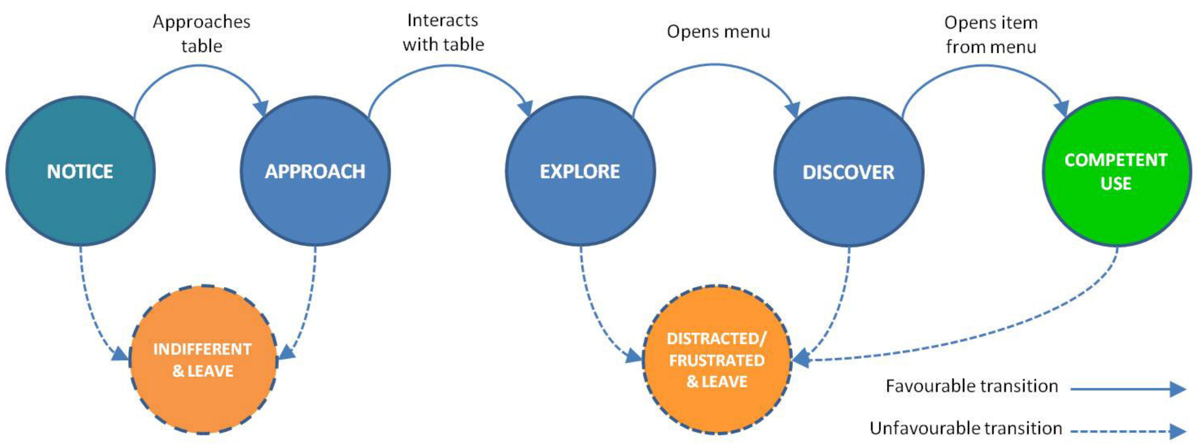


Figure 5.1: Interaction States Diagram (adapted from Cheung (2011))

The favourable states of the interaction model are outlined as follows:

Notice: The user's focus of attention is on the table. The characteristic of this state is the user's obvious visual focus on the table or the accompanying signage. Identification of this state is based on the researcher's field notes.[8]

Approach: The user physically approaches the table. The characteristic of this state is the user's physical approach to the table. Identification of this state is based on the user stepping into camera view.

Explore: The user makes intentional physical contact with the table (with the interactive or non-interactive areas). Characteristics of this state are the user playfully interacts with the table in an explorative manner.

[8] The only source of data pertaining to the 'Notice' state of the interaction model was the researcher's field notes. As this data could not be corroborated with any of the other sources (video or log files), this state was not analyzed in detail. At this state, participants were not in camera view and since no interaction with the table occurred, no interactions were logged.

Identification of this state is based on the user making contact with the table as captured by the video or log data.

Discover: The user purposely engages with the content on the table. Characteristics of this are the user's first correct, as intended by the system designers, interactions with the table content. Identification of this state is based on the user opening a menu or interacting with an open item (video or image from the menu) on the table, as captured by the video and log data.

Competent Use: The user understands the purpose of the menu. Characteristics of this state are the user browsing through the menu or opening an item. Identification of this state is the user opening an item from the menu as captured by the video and log data.

The "unfavourable" states, 'Indifferent & Leave' and 'Distracted/Frustrated & Leave', shown in orange in Figure 5.1, represent the interaction exit points. Users transition to these states when they do not successfully move onto the next favourable state and leave the system. For example, when a user notices the digital tabletop and chooses not to approach the system; this user transitions from 'Notice' to the 'Indifferent & Leave' state. Analysis of these unfavourable states is not described within the scope of these research findings because no data was gathered regarding participants' motivations for terminating interaction with the digital tabletop. Multiple factors such as other museum exhibits or loss of interest could have influenced their transition to these exit or unfavourable states.

As previously described in Chapter 1, discoverability can be split into discoverability of the system as a whole, and discoverability of the system features. Since the 'Notice' and 'Approach' states were not explicitly captured in the data and therefore not thoroughly analyzed, the analysis process and findings presented in this chapter focus primarily on the discovery of the system features, in particular, the system menu. The 'Engaged' state from Cheung's original model was therefore split into two separate states: 'Explore' and 'Discover'. The separation of these two states was based on the study data and resulted in a more detailed analysis of the discovery process as outlined in this chapter.

The refined interaction model, shown in Figure 5.1, provides a roadmap for the findings presented in this chapter with particular attention to the states and transitions between: 'Approach', 'Explore', and ‘Discover’. The findings focus on comparisons of the different menu invocation conditions throughout the states and transitions. First, from the ‘Approach’ to ‘Explore’ states, initial interactions with the digital tabletop are described. Next, from the ‘Explore’ to the ‘Discover’ states, menu invocation interactions are presented. Finally, from the ‘Discover’ to ‘Competent Use’ states, interactions with the crescent menu are discussed.

5.1 Approach to Explore

When users first approached the digital tabletop, groups either glanced around the system and surroundings prior to taking action or took action immediately. These actions were either interacting with the system or leaving without interaction. Delay of action was often caused by users looking around the physical table (for example, looking for a physical ‘start’ button) or reading the consent signage. In some cases, users were deterred by the consent signage and left without interaction. Users that interacted with the table transitioned from the ‘Approach’ to the ‘Explore’ state. Interaction was characterized as the user intentionally making contact with the table; this included looking around the physical tabletop and trying to find a button or tapping on the interactive surface of the digital tabletop. With a small number of groups, users interacted with the digital tabletop thinking it controlled the motion wall situated immediately across from the table. To compare the menu invocation conditions across the transition from the ‘Approach’ to the ‘Explore’ state, the location of user groups’ first touches with the interactive screen, the length of time of the ‘Explore’ state, and users’ interaction with the animation were examined.

5.1.1 First Touches

The first tabletop interaction of each user group is summarized in Table 5.1 and visualized in Figure 5.2 across all menu invocation conditions. Each point represents the location of the first touch point of each user group on the interactive surface. These points are categorized into four categories: invocation element, floating image, open space, and passing tap. ‘Invocation element’ points represent users that first tapped on the invocation element (border or button). Due to the technical limitations of the digital tabletop (further discussed in Section 6.3.2), not all touches resulted in a menu invocation. There were 9 occurrences in total: 1 with border and animation, 2 with buttons and animation, 1 with border, and 5 with buttons. Based on video and field note data verification however, these ‘technical error’ points of contact were still categorized as ‘invocation element’ as the user’s intended interaction was correct, however the system did not respond correctly. ‘Floating image' points are only relevant for conditions with animation present as they represent users that first tapped on a floating image, although these elements were non-interactive. 'Open space' points represent users that tapped in empty spaces of the screen that contain no invocation elements or floating images. The last category, 'passing taps' is not shown in Table 5.1 or Figure 5.2. These points were categorized as groups that tapped on the table while walking or running by and not stopping nor focusing their attention on the table. Most of these types of interactions were children running by the table while dragging a hand across the surface. Often these interactions were too quick to be recognized by the system; all had no subsequent interaction. 42 groups were identified as 'passing taps' interaction. As these interactions were irregular or indeterminate, they were omitted from the analysis. All subsequent analysis was based on the remaining 145 groups.

The orientation of the table shown in Figure 5.2 is identical to that depicted in Figure 4.5; the left side of the table is situated very close to a wall and the main corridor of the museum floor is to the right of the table. As Figure 5.2 shows, most first touch points were located to right of the tabletop screen, close to where users first approached the table. Although this finding is somewhat expected and influenced by the position of the table with respect to the visitor traffic, it also suggests that users tended to first interact with what was within immediate reach.

Table 5.1: Summary of All Groups' First Tabletop Interactions

Condition	Floating Image	Open Space	Invocation Element
Border + Animation	11	21	1
Buttons + Animation	13	28	3
Border	N/A	29	1
Buttons	N/A	29	9

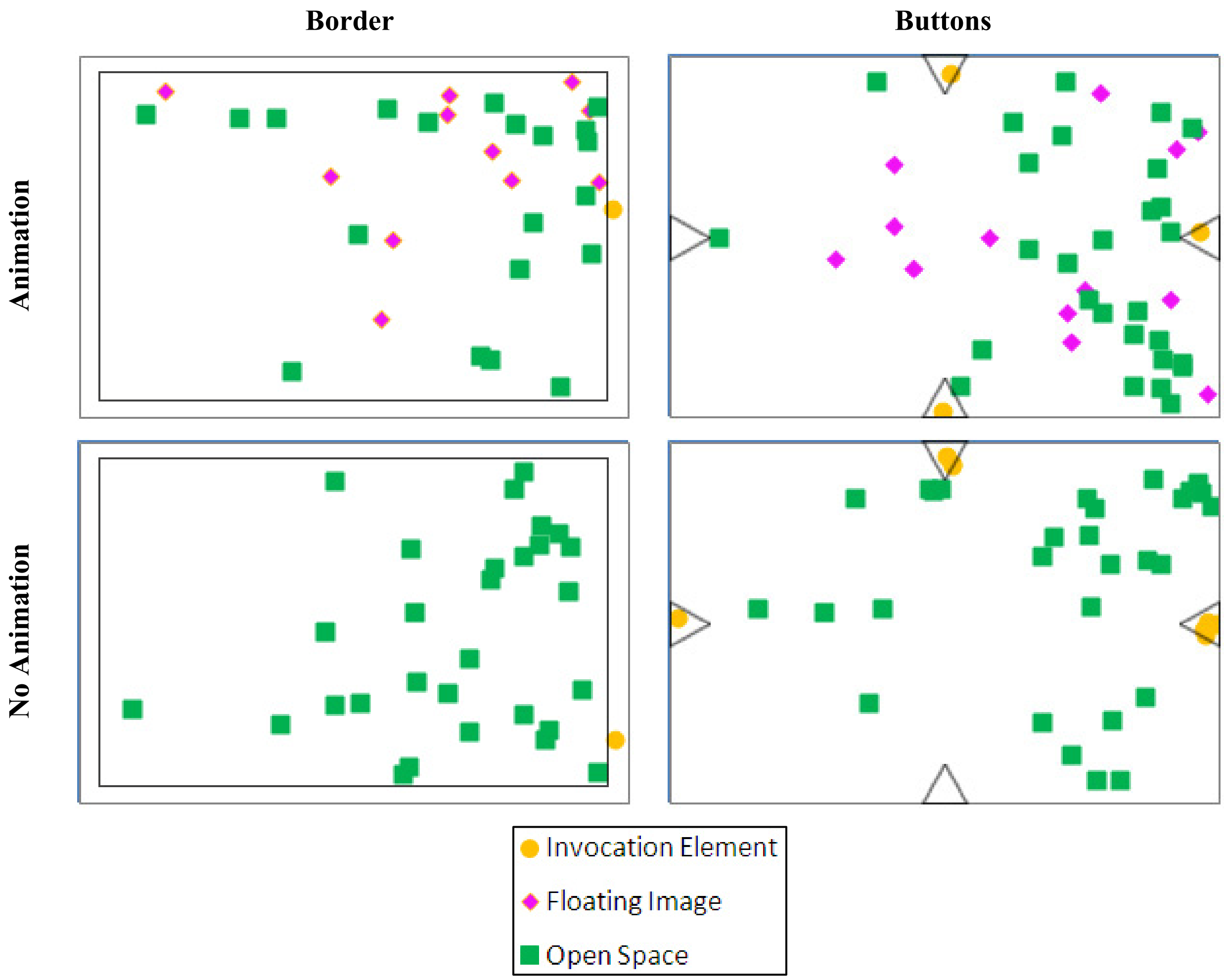


Figure 5.2: Location of users' first touches

In all conditions, the majority of users' first touches were on the open space of the screen (107 out of 145 groups). During the 'Explore' state, the primary activity was to determine the purpose or use of the system. Observations suggest that users first tapped the screen to test if the digital tabletop was interactive. An interesting observation was the difference in how adults versus children first interacted with the system. Adults tended to cautiously tap the table with one finger and paused for a response from the system. Most children, on the other hand, were much less cautious and interacted with the table with their full palm (and sometimes two hands) while rubbing or hitting around randomly.

Interaction with the floating images and invocation elements are outlined in more detail in Sections 5.1.3 and 5.2.1 respectively.

5.1.2 Duration of 'Explore'

To better understand the 'Explore' state, a comparison of the length of time spent in this state across all menu conditions was calculated. Table 5.2 outlines the mean time of the 'Explore' state for each condition. This time indicates how long a group, on average, spent interacting with the digital tabletop before invoking a menu, or leaving. A two-way ANOVA comparing the 'Explore' time across conditions found no significant differences across invocation type ($F(1,12)=0.42$, $p=.53$, *n.s.*), animation ($F(1,12)=0.05$, $p=.83$, *n.s.*), nor an interaction between invocation type and animation ($F(1,12)=0.05$, $p=.83$, *n.s.*). None of the study conditions has a significantly shorter 'Explore' time compared to the others.

Table 5.2: Mean 'Explore' time per group (in seconds)

	Border	Buttons
Animation	11 sec. (Standard Deviation: 7 sec.)	10 sec. (Standard Deviation: 9 sec.)
No Animation	12 sec. (Standard Deviation: 11 sec.)	10 sec. (Standard Deviation: 13 sec.)

Visualizations were created of the duration of all states for each group and condition to better understand these states, for example Figure 5.3 shows the timelines for two groups. Visualization timelines for all groups are provided in Appendix E. Analysis of these timelines found that overall, groups with shorter 'Explore' times transitioned to the 'Discover' state. This suggests that users with longer 'Explore' times often "gave up" and ceased interaction with the digital tabletop because they could not determine its purpose or find interactive content. For example, Figure 5.3 shows a group with a long 'Explore' time of 28 seconds (Group A) versus a group with a short 'Explore' time of 4 seconds (Group B). Of these groups, only Group B transitions to the 'Discover' and subsequently 'Competent Use' states.

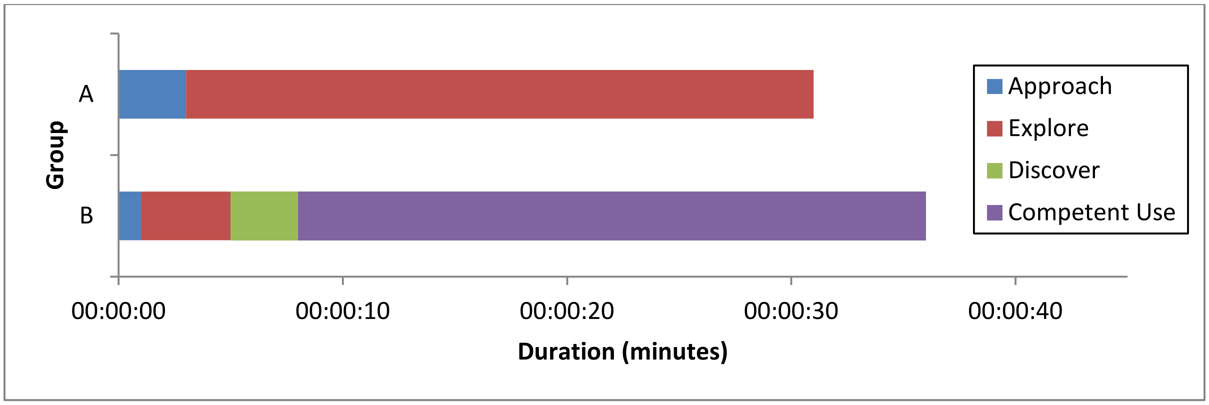


Figure 5.3: User Timelines

During the 'Explore' state, many users pondered out loud, "*what does this do?*"or *"does this thing do anything?"* If they were intrigued enough, they would continue to explore on the table by continuing to tap on the screen until they either discovered something (i.e. invoked the crescent menu) or left and ceased interaction. Some user groups paused during the 'Explore' state to read or re-read the consent and informational signage, perhaps seeking instructions on how to use the digital tabletop. Others called over other people to join in their interaction.

In exploring interaction with the digital tabletop, user groups either randomly tapped on the table without obvious direction or interacted with (e.g. tap or drag) the displayed interface elements, such as tapping the floating images. With the groups that interacted randomly without obvious direction, some notable interactions include a child that "hugged" the table and another child rubbing his hands in the motion of windshield wipers, both shown in Figure 5.4.

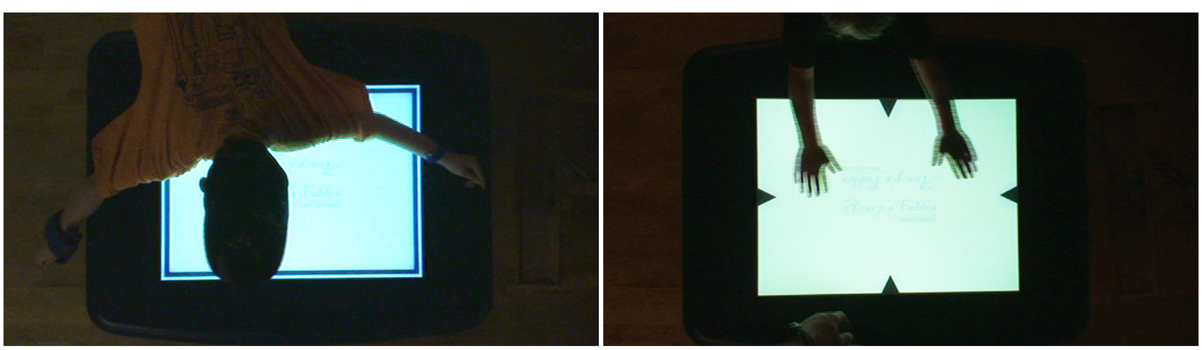


Figure 5.4: Explorative interactions on the digital tabletop

In these cases, their interactions appeared to be random searches to determine the purpose of the system. If these groups invoked a menu, they would often end their search with one user exclaiming "*oh I found something!"* to the other group members. With groups whose interactions appeared primarily guided by the interface elements, their interactions mainly included tapping or trying to drag the floating images and, when displayed, trying to interact with the pop-up animation. These interactions are discussed in more detail in the following section. For the buttons condition, with and without animation present, many users tried to drag the buttons towards the center of the table. This observation suggests that users may have interpreted the triangular button as an arrow pointing inward, suggesting dragging inward. Consistent with the groups' "first touch" interactions discussed in the previous section, explorative interactions with the invocation element were not as common in the border condition, as later reflected in Section 5.2.2.

5.1.3 Interactions with Animation

As part of users' explorative interactions, groups interacted with the floating images and the pop-up animation. The following is a discussion of these interactions. It only considers the animation present conditions, including both the border and buttons conditions.

Floating Images Animation

Overall, 51.3% of groups interacted with the floating images. These interactions occurred at any point during the 'Explore' state and consisted of tapping or trying to drag the images. This finding suggests that many users assumed that the floating images were interactive. Additionally, even though its intention was to hint to users that there was content to interact with on the table, and it could be accessed at the edge of the table, this animation may have distracted users by instead inviting interaction to the floating images. The means of users' interactions with animation across conditions are outlined in Table 5.3. An independent sample t-test comparing interaction occurrences with floating images across border and button conditions found no significant difference across conditions ($t(6)=0.51$, $p=.63$, *n.s.*).

Table 5.3: Percentage of groups that interacted with animation

		Mean	Standard Deviation
Interacted with floating images	**Border**	44.4%	37.8%
	Buttons	54.5%	11.8%
Interacted with pop-up animation	**Border**	30.0%	13.5%
	Buttons	56.3%	13.8%
Invoked a menu from the pop-up	**Border**	87.5%	25.0%
	Buttons	29.2%	47.9%

Pop-up Animation

Due to the technical limitations of the SMART Table, not all touch interactions were properly logged and detected. As a result, not all first interactions triggered a pop-up animation. Analysis of user interaction with the pop-up animation was therefore adjusted to only consider groups that successfully triggered a pop-up animation (64 of 78 groups). Overall, 42.2% of these groups interacted with the pop-up animation when invoked. These interactions including tapping or dragging the pop-up, or nearby the pop-up location. Of the groups that interacted with the pop-up, 51.9% of them successfully invoked a menu from this interaction. These findings suggest that across both invocation conditions, the majority of user groups either did not notice the pop-up, or were not persuaded to interact with it. For those that did notice and interact with the pop-up, more than half, across both invocation conditions, subsequently performed the successful action to invoke a menu. An independent sample t-test comparing interaction with the pop-up animation found a significant difference across invocation conditions ($t(6)=2.72$, $p=.04$). More groups interacted with the pop-up in the buttons condition (mean(M)=56.3%, standard deviation(SD)=13.8%) than in the border condition (M=30.0%, SD=13.5%). An independent sample t-test comparing successful invocation of the menu from the pop-up interactions found no significant difference across invocation conditions ($t(6)=2.16$, $p=.07$, *n.s.*) indicating that neither of the invocation conditions was more effective at guiding users' actions. This finding suggests that in the buttons conditions, although the pop-up animation may have been more attractive, it did not more effectively guide users' actions to invoke a menu.

5.2 Explore to Discover

User groups that invoked a menu transitioned into the 'Discover' state. To compare the menu invocation conditions across the 'Explore' to 'Discover' transition, the percentage of groups that invoked at least one menu per group and accompanying scenarios were examined.

5.2.1 Menu Invocations

Users that first tapped the invocation element immediately transitioned from the 'Explore' to the 'Discover' state. The percentage of groups whose first touch was on an invocation element is shown in Figure 5.5. A two-way ANOVA comparing these data found a significant difference across invocation types ($F(1,12)=4.89$, $p=.047$). There was no significant difference found across animation conditions ($F(1,12)=2.42$, $p=.15$, *n.s.*) nor was there a significant interaction between invocation type and animation conditions ($F(1,12)=2.05$, $p=.18$, *n.s.*). These results show that when comparing the border to buttons invocation conditions, significantly more groups first tapped the buttons (M=14.0%, SD=14.6%) than the border (M=2.8%, SD=5.3%) suggesting that the buttons design initially attracted interaction more effectively than the border design for menu invocation.

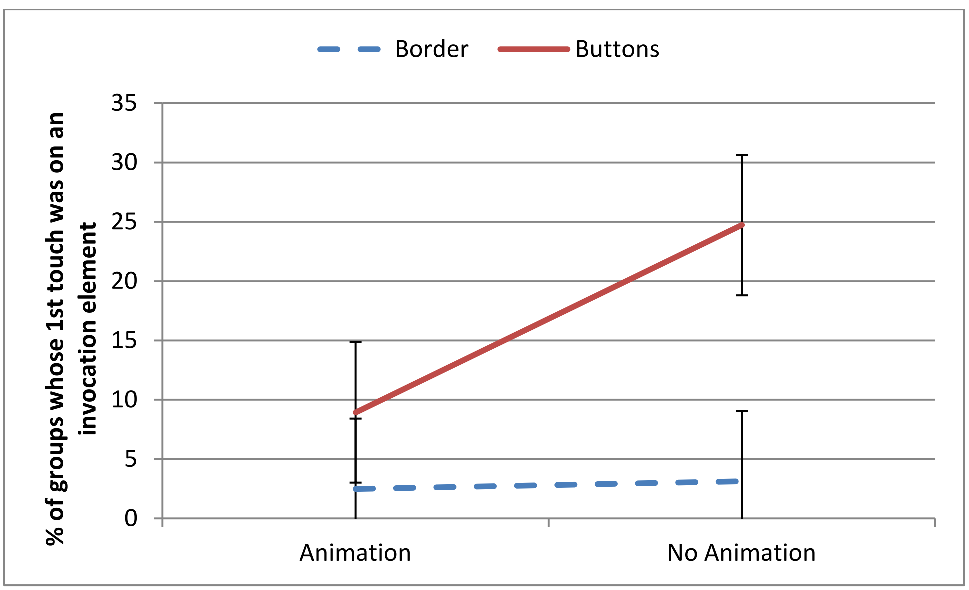
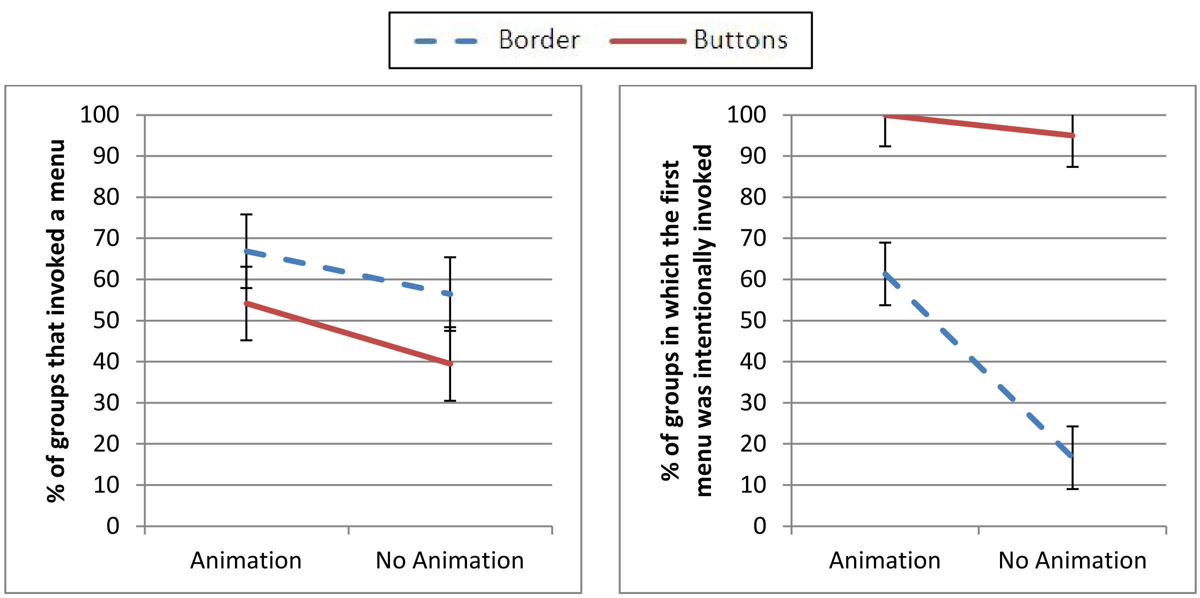


Figure 5.5: Percentage of groups whose 1st touch was on an invocation element (error bars based on standard error)

Although there was no significant difference between the presence and absence of animation, Figure 5.5 suggests an interesting trend. For the buttons invocation condition, more groups first tapped the invocation element when there was no animation than when there was animation. Despite the original intention of including animation as a means of improving menu discoverability, these results suggest that animation may have in fact impeded or distracted menu invocation in the buttons condition. This will be further discussed in Chapter 6.

The video analysis revealed interesting observations of *how* users interacted with the invocation element. For the scope of this research, a menu was invoked if the user tapped on the invocation element. Some users used a variety of other gestures to try to invoke a menu, the most popular being trying to drag or dwelling (i.e. touching and holding for a few seconds) on the invocation element.

Not all user groups transitioned from the 'Explore' to the 'Discover' state on their first touch interaction. Some invoked a menu after much exploration. To more generally compare the menu conditions, the percentage of groups that invoked menus was calculated and graphed across all conditions (see Figure 5.6a). A two-way ANOVA comparing these data found no significant effects due to invocation type ($F(1,12)=1.38$, $p=.26$, *n.s.*), animation ($F(1,12)=0.99$, $p=.34$, *n.s.*), or interactions ($F(1,12)=0.03$, $p=.87$, *n.s.*). These results indicate that no condition significantly outperformed the others in terms of number of groups that invoked a menu.



a) b)

Figure 5.6: a) Percentage of groups that invoke a menu; b) Percentage of groups in which the first menu was intentionally invoked (error bars based on standard error)

5.2.2 Intentional Menu Invocation

Closer examination of *how* users invoked menus revealed that there was a distinction between intentional and unintentional menu invocations. Intentional menu invocations were identified as invocations as a result of purposeful interaction while the user's focus of attention was on the invocation element being interacted with. Unintentional menu invocations were identified as invocations as a result of an interaction when the user's focus of attention was *not* on the invocation element being interacted with or as a result of an interaction intended for another item. Examples of interactions resulting in unintentional menu invocations are a user resting or leaning his/her elbow/arm on the surface of the table, and a user dragging an open image (menu content) around the screen.

Figure 5.6b shows the percentage of groups in which the first menu was intentionally invoked based on number of groups that invoked a menu. The *first* menu is specified because it is the first menu per group that is invoked that demonstrates discoverability. Subsequent menu invocations are influenced by learning effects. A two-way ANOVA comparing these data across conditions found a significant difference across both invocation types ($F(1,12)=41.06$, $p<.01$) and animation ($F(1,12)=7.86$, $p=.02$). There was also a marginally significant interaction effect between invocation type and animation ($F(1,12)=4.58$, $p=.054$). Examination of the data reveals that across the invocation condition, significantly more user groups intentionally invoked a menu in the buttons condition (M=97.2%, SD=7.9%) in comparison to the border condition (M=43.6%, SD=30.3%). As Figure 5.6b shows on average in the buttons condition, if a group invoked a menu, the first menu was intentionally invoked more than 90% of the time. Additionally across the animation condition, significantly more user groups intentionally invoked a menu with the presence of animation (M=82.1%, SD=26.2%) than without (M=56.7%, SD=40.3%).

Further investigation of the marginal interaction effect was conducted for each invocation type across animation. An independent sample t-test comparing intentional menu invocation with the border condition found a significant difference across animation conditions ($t(6)=2.62$, $p=.04$). No significant difference was found with the buttons condition ($t(6)=1.00$, $p=.36$, *n.s.*). These results indicate that animation had a greater impact with the border condition than with buttons; more groups in the border condition intentionally invoked a menu when animation was present (M=64.3%, SD=27.4%) than without (M=22.9%, SD=15.8%).

5.3 Discover to Competent Use

After invoking a crescent menu, users transitioned from 'Discover' to 'Competent Use' states when they opened an item from the menu. For the scope of this study, this task marked competent use because the purpose of the experimental application was to showcase various images and videos. Opening an item from the menu indicated that the user achieved the intended purpose of the application. All invocation conditions resulted in invocation of the crescent menu and therefore comparisons across these conditions are not relevant for this transition. Findings for this transition were based on crescent menu use.

5.3.1 Crescent Menu Interactions

From the number of groups that invoked a menu, 80.3% opened at least one menu item. The mean 'Discover' time was 10 seconds with a standard deviation of 11 seconds. This time describes the average time taken to browse and select an item from the menu. The length of time interacting with the menu and its content spent by each group ('Competent Use' time) varied, as shown in the user timelines included in Appendix E. The length of use with a museum exhibit is influenced by users' level of engagement with the content (Hornecker & Stifter, 2006) and is therefore a variable not considered for the scope of this research.

When a menu was invoked, users within a group often crowded around the menu or reached towards the menu from their current position to interact with the single menu. There was often a delay before users discovered that multiple menus could be invoked at the same time. This was more frequent with the border condition than the buttons condition. Subsequent menu invocations within a group were often from users trying to mimic the gesture or interaction that the first user performed to invoke the menu. With some groups, the first user explicitly showed how he/she invoked the menu. When navigating within the menu, users were quick to discover that tapping the category buttons revealed a submenu layer. All users used the button arrows to scroll within a menu level and often only discovered the drag to scroll gesture by accident or unintended gesture. To open a menu item, the majority of user groups quickly discovered that tapping the thumbnail of the image opened an enlarged version in front of the menu. Some groups did however try to drag the thumbnail off of the menu in order to open it. All groups eventually figured out that tapping was the correct gesture. With both the arrow buttons and thumbnails, a gray-out effect was applied to the button when it was inactive – no more content to scroll or the thumbnail image was already open. In almost all groups, users tapped (often repeatedly) on the grayed-out buttons expecting interaction.

5.4 Chapter Summary

An observational study was conducted to evaluate the menu invocation designs. Based on analysis of this study data, a refined interaction model outlining the states that study participants transitioned through was created. Data analysis focused on the states and transitions between 'Approach', 'Explore' and 'Discover'. This analysis revealed differences across invocation type and animation throughout various interaction states. These differences draw particular attention to the purpose of and interactions with the two animations employed in this study, as well as the effect of invocation type and animation on intentional menu invocation. The following chapter summarizes and discusses the implications of these findings.

Chapter 6
Discussion

This chapter summarizes the results and discusses the implications of the findings presented in Chapter 5. It begins with a discussion and comparison of the proposed menu invocations designs. Next, the results of the comparison and other notable findings are situated within the interaction model applied in this research. These results are then extended into recommendations for improving menu discoverability. Finally, the limitations of the study method and technology are discussed.

6.1 Comparing the Menu Invocation Designs

Invocation type and animation were introduced as two design factors that formed the four menu invocation designs evaluated in this research: border with animation, buttons with animation, border without animation, and buttons without animation. The following is a discussion of these menu invocation design factors.

6.1.1 Invocation Type

Two invocation methods were compared in this research: border and buttons. The buttons design represented the use of a more commonly used interface element while the border design proposed an invocation method tailored to the horizontal orientation of digital tabletops.

Analysis of users' first interactions with the digital tabletop revealed that the majority of users first interacted with the open space or floating images, with a small percentage first interacting with the invocation elements. This finding suggests that most users were not initially drawn to the border or buttons. Of the users that did interact with the invocation elements first, significantly more were drawn to the buttons than the border. Although the same colouring and glow effect was applied to both the border and buttons, users tended to recognize the button as an interactive interface element more easily than the border element. This finding suggests that users were initially more attracted to the buttons design. Each button obtruded from the edge of the table very obviously suggesting a "place marker" for a potential user. This may have been more effective at attracting and guiding users' interactions. The border design on the other hand was consistent all around the table and may have visually blended into the table edge, therefore making it difficult to distinguish as an interactive GUI element.

When looking at groups that invoked at least one menu, no significant differences were found across conditions. An examination of *intentional* versus *unintentional* menu invocation however, revealed that significantly more groups intentionally invoked a menu with the buttons conditions than with the border condition. These findings suggest that the buttons design was more discoverable for menu invocation. This result was likely due to the visual protrusion of the buttons, or the familiarity of most users with buttons as a GUI element. Contrarily, a border is typically used to demarcate space on an interface and is not as commonly viewed as interactive. The higher frequency of border menu invocations in the raw data (though not statistically significant) was likely due to opportunistic accidents such as leaning on the table or random explorative gestures.

Although a simple aesthetic design for invocation conditions (black with blue glow) was chosen for this study for consistency across conditions and to control for possible confounding factors, it may have affected users' recognition of the graphical elements. A flat aesthetic design (no shading or shadows) was applied to the buttons used in this study. This is unlike the classic design of buttons that mimics the physical button design, by using beveling or shading to make it appear 3-dimensional. The 3-dimensional effect is typically applied to a GUI button to imply the affordance of pushing. It is notable however, that with the rise of touch interfaces, flat aesthetic designs are becoming more common. For example, the Microsoft Windows Phone[9] uses a flat interface design. Due to the flat colouring of the buttons used in this study, it therefore cannot be soundly concluded whether the buttons design was the more discoverable design due the use of a common interface element – a button – or, due to its more distinguishing appearance on the screen compared to the border design. Some users may not have initially recognized the triangular shape of the button as a GUI button, but instead just recognized it as a distinguishing and noticeable element on the screen. Further studies are required to distinguish between these two possible influences.

The border design was initially thought to be less recognizable as an interactive element due to its classic use as a space divider. With the rise of mobile computing that uses border-based interactions (e.g. BlackBerry PlayBook[10]) however, users' experiences and perceptions of the GUI elements may change and thereby influence how they discover and interact with interactive systems. The design of (perceived) affordances in the scope of interface design would need to account for these experiences.

[9] http://www.windowsphone.com
[10] http://ca.blackberry.com/playbook-tablet/

To better understand the influence of differing experiences on discoverability, further studies are required.

6.1.2 Animation

Animation was applied in the menu invocation designs with the primary goals of informing users of the existence of menus and guiding users in how to invoke menus on the digital tabletop.

The examination of where users first interacted with the digital tabletop found that most users first tapped on the open space of the display. This was consistent with and without the presence of animation. Additionally, the location of these first touches was primarily by the sides of the table nearest to main user traffic flow. These findings suggest that users tended to first interact with what was reachable. The data analysis also showed that users' first interactions with the table were to test if the table was interactive – often tapping or rubbing the table and then pausing for a response. When animation was present, a small subset of groups first tried to interact with the floating images.

The floating images animation was intended to attract attention to the table through the use of visual movement. Additionally, the goal of this animation was to inform users that information was stored on the table and where they might find this information by having the images drift into the edges of the table. The content of the floating images could then be found within the menu if invoked from the edge of the table. Based on the study findings, the floating images attracted attention as the majority of users tried to interact with them while exploring interaction with the table. This animation did not however appear to successfully guide users to the menus as the findings did not indicate that users noticed the trail of the floating images. Furthermore, as discussed in Section 6.1.1, more users first interacted with the buttons than the border. A notable difference with respect to this finding is that more users first interacted with the buttons without the use of animation than with. This finding suggests that when the buttons invocation type was used, the floating images animation may have distracted users' attention from the invocation element, despite its original intention of assisting menu discoverability.

The pop-up animation was used for similar purposes with the added purpose of directing users' attention to the invocation element (border or buttons), particularly if they first interacted elsewhere on the screen. Results from the study found that of the users that did trigger a pop-up animation, some of them tried to interact with it. This indicates that the pop-up animation did attract some attention. This percentage was not however, significant. Looking across invocation conditions, more groups interacted with the pop-up in the buttons condition compared to the border condition. Users may have more easily noticed the pop-ups since they appeared at the location of a button which already attracted attention due to its more distinctive shape on the screen compared to the border design. It is important to note that only the number of users that *interacted* with the pop-up was measured and not the total number of users that *noticed* the pop-up. It is possible that users may have noticed the pop-up, however chose not to interact with it. Without the use of gaze-tracking, attention to the pop-up animation could not be accurately measured. Of the users' that interacted with the pop-up animation, a significant number of them successfully invoked a menu across invocation conditions. This suggests that when the pop-up animation was noticed and users interacted with it, it was effective at guiding users' actions in invoking a menu.

Looking at the distinction between intentional and unintentional menu invocation again, the analysis results found that with the inclusion of animation significantly more groups intentionally invoked a menu. This difference was determined to be of greater significance with the border condition than buttons condition. These findings suggest that animation is helpful for menu discoverability; however, they do not distinguish between the influence of the floating images and pop-up animation.

Results from the data analysis suggest that each of the animations investigated in this study, floating images and pop-up, served different purposes. The floating images animation helped to attract users to the table. This animation was continuous and unaffected by users' interaction (until a menu was invoked). Its unresponsive nature makes it most suitable for the 'Attract' state – to entice users to engage with the system. The pop-up animation served to help guide users' interactions. This animation only appeared when a user tapped on the table and was therefore a responsive animation. The feedback it provides makes it most suitable for the 'Explore', 'Discover' and subsequent 'Competent Use' states. As these two animations were evaluated together in this research, further studies to investigate their individual influence on overall menu discoverability and their specific roles in the interaction model are required.

6.1.3 Summary

Overall, buttons with the use of animation was found to be the most discoverable menu invocation design. Results from comparing the border to buttons design found buttons to be more discoverable. As a common GUI element and using a more distinguishable design, users more easily identified buttons as interactive elements. As a result, more users intentionally invoked a menu with the buttons design. The results regarding animation from this research supports findings from previous research of the positive correlation between animation and attention (Bodenhausen & Hugenberg, 2009; Palmer, 1999). When discovered, the pop-up animation was helpful in guiding users' actions towards invoking a menu. The floating images animation was useful for attracting attention and interaction; however results suggest that it may have also distracted users from locating the invocation element.

6.2 Design Recommendations

In addition to elucidating the potential of the tested interfaces as discoverable menu invocation designs, the analysis and findings from this research point to a set of design recommendations as outlined in the following three subsections.

6.2.1 Menu Invocation Recommendations

The comparisons of the menu invocation designs evaluated in this research provided several implications for the design of future menu invocation techniques, specifically with respect to the use of animation and invocation elements. These implications are summarized in the following three recommendations for discoverable menu invocation design:

- *Immediate feedback to exploratory interactions:* Users' first interactions with the digital tabletop were often to test if the table was interactive – tapping or rubbing the table and then pausing for a response. With the presence of animation, users tried to interact with the floating images. It is therefore recommended that in addition to using animation to draw attention, these animations should support interaction and respond to users' interactions to engage users into further action.

- *Use of discernible interface elements:* The study results revealed that the buttons design was significantly more discoverable than the border design. This was posited to be due its distinguishable shape in the interface and use of a common GUI element – a button. This finding suggests that the use of more universal GUI elements, such as the button which is already perceived to afford interaction, particularly one that has high visible contrast, facilitates discoverability. This is particularly important for public settings where users are typically novice users. Special attention should be made however to ensure that these elements are used such that they do not diverge so much from their original design that they become unrecognizable, while still taking heed to the digital tabletop interface considerations, such as orientation.

- *Animation as a guide:* The study results also revealed that animation, especially the pop-up animation, was effective at guiding users' actions. Animation is therefore recommended for assisting users to discover new interactions, or even reinforcing existing ones. This suggestion coincides with the purpose and recommended use of self-revealing gestures (Brandl et al., 2008; Wigdor & Wixon, 2011).

6.2.2 Menu Recommendations

Although the crescent menu employed in this study was not formally evaluated, a few common problems regarding its use were identified during the data analysis. The following are recommendations on improvements to the crescent menu design based on this analysis:

- *Increase contrast between active and inactive buttons*: observations from the study revealed that users repeatedly tried to tap inactive buttons which had a grayed-out effect applied to them, suggesting that users did not notice this visual distinction. Increasing the contrast between active and inactive buttons, such as making inactive buttons translucent in addition to applying a grayed-out effect, may help with users to better distinguish between these two button states.

- *Support drag to open gestures for both menu and menu items:* observations also revealed that in addition to the intended tap-to-open design employed in this research, many users tried using a drag gesture to open the menu and menu items. Support of the drag gesture, in addition to the tap gesture, would help overcome this interaction issue. This suggestion is also motivated by Hinrich and Carpendale's (2011) recommendation to support of a variety of multi-touch gestures in user interactions.

6.2.3 Interaction Model

Users' interactions with the digital tabletop in this research transitioned from noticing the system ('Notice') to understanding the purpose and use of the system ('Competent Use') through a series of three states ('Approach', 'Explore', and 'Discover'), as presented in Figure 5.1. The findings from this research support this model with particular attention to these central three states and transitions between 'Approach', 'Explore', 'Discover'. The transition from 'Approach' to 'Explore' focused on inviting users to interact with the digital tabletop. The transition from 'Explore' to 'Discover' focused on correctly guiding user interaction to discover available system purpose and capabilities. Both of these transitions were investigated with the use of different invocation designs and presence or absence of animation.

This model was built atop Cheung's (2011) interaction model and further extends it to encompass the discoverability process users transition through when interacting with a digital tabletop in a public setting. Based on the model presented in this thesis, it is proposed to decompose the 'Engaged' state from Cheung's model into two sub-states – 'Explore' and 'Discover'. These two states describe how users were attracted and guided to, and thereby discovered, how to invoke a menu on the digital tabletop. The context of this recommendation is limited to context of this research, however further research is recommended to investigate the applicability of this expanded model to other contexts.

6.3 Limitations

As with any user or experimental study, there are limitations. The following is a discussion of the limitations of the study method and the technology employed in this study.

6.3.1 Limitations of the Method

A fundamental dilemma of research methods is that no singular method can maximize precision, realism and generalizability (McGrath, 1984). This concept is depicted in McGrath's Research Strategies Circumplex, previously shown in Figure 4.1. The study described in this thesis used a field experiment methodology, and therefore tended towards realism and unobtrusive observations as desired, however the study was also limited in other measures.

First, the location and position of the digital tabletop posed some limitations. The museum is targeted to children and young families and therefore the sample population was limited towards these groups. Additionally, the exact location of the digital tabletop within the museum was restricted to the space availability at the time of study. The digital tabletop was set up such that only three of the four sides were easily accessible and therefore influenced how users could approach the table. Furthermore, surrounding museum exhibits may have influenced users' behaviour with the digital tabletop. For example, some groups thought that the digital tabletop controlled a motion wall located nearby. These exhibits may have also distracted users from interacting or interrupted their interaction with the digital tabletop.

Second, the unobtrusive nature and lack of control of various factors, as true of any field-based study or experiment, posed some additional limitations. To maintain the realism of the setting, participants were never explicitly invited to interact with the digital table nor informed verbally that the area was being observed. To comply with ethical protocol however, an informed consent sign was posted by the table. This factor may have deterred some people from interacting with the system, rather than the system itself being uninteresting to them. Additionally, to unobtrusively gather data, a video camcorder was installed directly above the digital tabletop. This position was purposely selected as it captured interaction on and around the table well, without capturing the faces of participants (as outlined by ethical procedures). This camera angle did not however, capture possible observers or the exact moment that people actually noticed the digital tabletop from afar. As a result, some participants may have observed other users from a distance, for example while interacting with another exhibit, before approaching and interacting with the digital tabletop themselves. This would have influenced their experience and behaviour with the system as learning from observing may have occurred.

6.3.2 Technical Limitations

The SMART Table uses Frustrated Total Internal Reflection (Han, 2005) to detect touch interaction. With this technology, touch interactions near the border of the table are more difficult to accurately recognize than those near the center of table. Additionally, the pressure applied by the user when tapping the display of the table influences the probability of the touch point being properly detected by the system. Users were not informed of how to specifically interact with the SMART Table, and therefore there were variations in the pressure of touch interactions. Individual user differences in the pressure and location of their touch interactions resulted in some touches being undetected by the system. The public setting of the study also influenced the performance of the system. Unavoidably, multiple users on the table resulted in a build-up of dirt and grime on the screen (for example, fingerprints). Dirt on the table's screen can result in undetected touch interactions. Although the screen was cleaned throughout the study, it was impossible to clean the screen after each user group without disrupting the study.

6.4 Chapter Summary

This chapter discussed the findings presented in this thesis in the larger context of menu interaction and design. Based on comparisons across each study factor, invocation type and animation, the buttons invocation design with the use of animation was recommended as the most discoverable design. Implications of the study were summarized in a set of three menu invocation design recommendations towards discoverable design regarding the use of feedback, distinct GUI elements, and animation. Additionally, the limitations of the method and technology employed in this study were discussed.

Chapter 7
Conclusions

Ease of use with digital tabletops in public settings is contingent on how well the system invites and guides interaction. The same can be said for the interface design and individual GUI elements of these systems. One such interface element is menus. Prior to a menu being used however, it must first be discovered within the interface. Existing research pertaining to digital tabletop menu design, even general menu design, does not address this issue of discovering or opening a menu. The research presented in this thesis was motivated by this lack of attention given to the process of menu invocation, with a focus on the context of public settings.

Within this thesis, menu invocation designs for digital tabletops were presented and evaluated with a focus on their discoverability in public settings. Analysis of the study results revealed which tested factors contributed to discoverability. These findings are summarized below, along with a set of recommendations for the design of discoverable tabletop menus. As a little explored phenomenon, discoverability of tabletop interface functionality warrants further study beyond this initial study. Recommendations for future research directions are also discussed.

7.1 Research Objectives and Summary

The objectives of this research were to determine the existing techniques for designing discoverable digital tabletop menus; design a menu invocation design solution that encourages discoverability on digital tabletops in public settings; and evaluate the discoverability of the proposed menu invocation design. The first objective was addressed by reviewing literature related to digital tabletop interface design, public displays and interaction models, and digital tabletop menus (Chapter 2). This review identified a gap in the literature pertaining specifically to the discoverability of tabletop menus and other functionality.

The second research objective was addressed by designing a set of menu invocation designs (Chapter 3). The four proposed designs combined two design factors: invocation type and animation, creating a set of designs that included interactive border or buttons, with or without animation elements designed to attract and guide users.

Finally, the third objective was addressed through a user study evaluating the proposed designs (Chapters 4 and 5). An observational study in a museum was conducted. Study findings led to the following three contributions:

- **A discoverable menu invocation design solution.** Analysis of the study findings found buttons with the use of animation to be the most discoverable invocation design from the evaluated set. Buttons was found to be the more discoverable invocation design compared to the border design. Additionally, the use of animation was found to be useful for attraction and guiding users' interactions.
- **A set of menu invocation design recommendations for improving menu discoverability**. Comparisons of the study factors, invocation type and animation, led to the following three design recommendation for improving menu discoverability: provide immediate feedback to exploratory interactions, use discernible interface elements, and use animation as a guide.
- **An expanded interaction model with attention to the discovery process.** Study findings noted that when engaging with a public digital tabletop, participants transitioned through two key states before becoming competent with the system. To represent this discovery process, this research proposes to split the 'Engaged' state from Cheung's (2011) model into two sub-states: 'Explore' and 'Discover'.

7.2 Future Work

The results and conclusions presented in this thesis draw attention to a number of areas that warrant further study.

First, findings from this study suggest that the inclusion of animation is helpful for menu discoverability. Attention to the specific types of animation still requires further work. Future studies should look at comparing the discoverability of specific types of animation (e.g. floating images versus pop-up animation) and how they invite interactivity. Furthermore, the floating images and pop-up animation techniques applied in this research served different purposes: the first to attract, and the second to guide users. Further investigation with each technique is required to investigate how well the technique achieves its intended goal, and what other animation techniques could also accomplish that purpose.

Second, due to the context of this study, the sample population was primarily children. To generalize these findings to a larger sample group, similar studies should be conducted with varying sample populations. These studies could also investigate the interaction differences between different groups, for example adults versus children.

Third, this research focused on the discoverability of menus located along the table edge. It would be useful to investigate the effectiveness of the discoverability techniques proposed from this research when a digital tabletop has other types of menus or system functionality.

Finally, the refined interaction model proposed in this thesis applies for the context of this study. To evaluate and understand the model's implications for more general public contexts, further studies are required. These studies should take in consideration the effect of observers and how they may enter the model differently due to learning effects. Future work should also investigate how to account for specific social behaviours unique to public settings, such as personal inhibition/embarrassment with large crowds, in the interaction model and how these behaviours might affect the state transitions. Additionally, further investigations into the factors that motivate users to leave an interactive display and transition to the exit/unfavourable states of the interaction model are required.

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There are only 10 types of people in the world:
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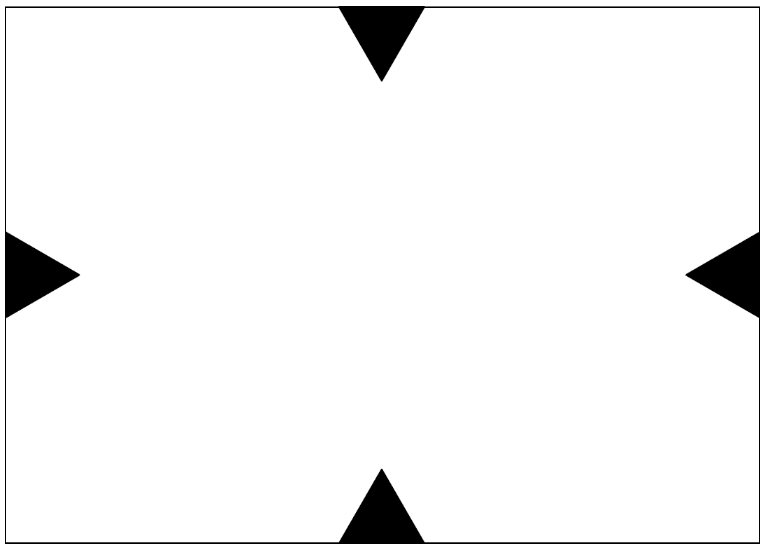
Appendix A

Crescent Menu and Menu Invocations Design Documentation

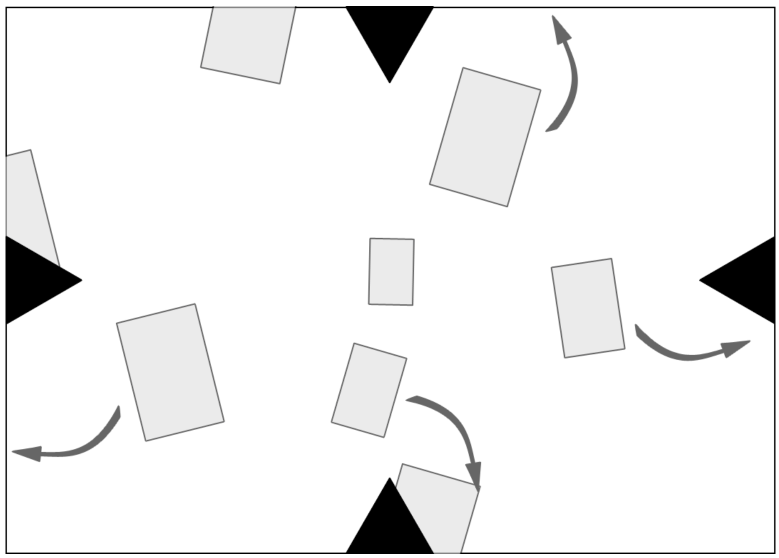
A.1 Menu Invocation Conditions

1. **Buttons: Pre-defined start areas**
   Glowing buttons on each side of the table denote where a menu can be invoked. Tapping on a triangle will make the selected button disappear and open a menu in that spot along the edge of the table and directed outwards (the menu will be horizontally-centered to the selected button).

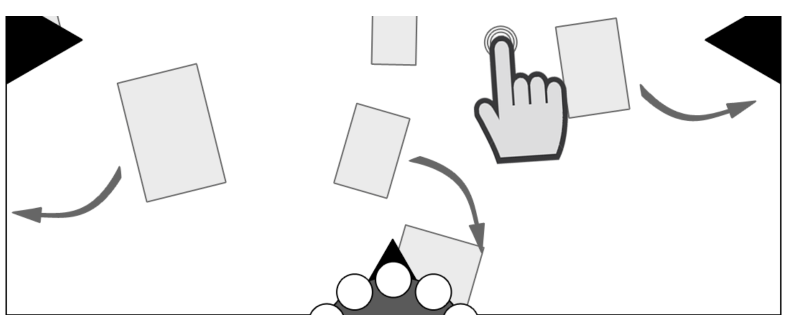


2. **Border: Glowing tap-anywhere border**
   A glowing border on the interactive area of the table entices users to tap on it. Tapping anywhere within the indicated border will invoke a menu in the tapped spot along the edge of the table and directed outwards (the menu will be horizontally-centered to the tapped spot).

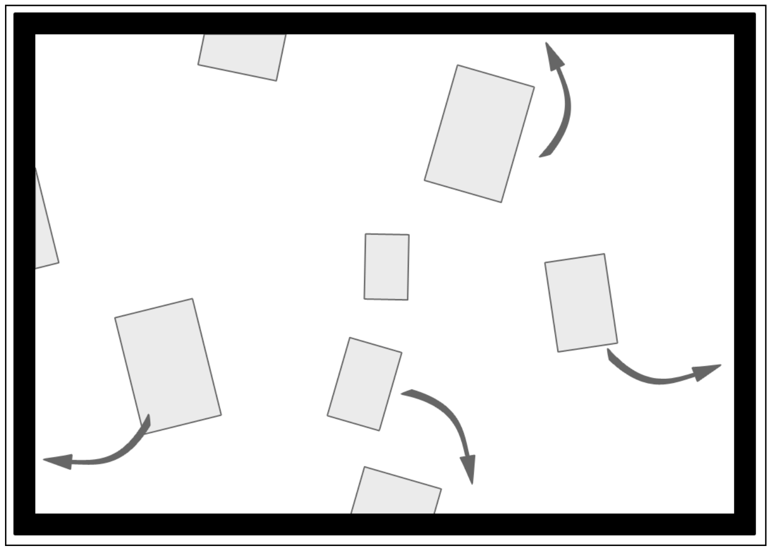
3. **Buttons + Animation**
In the attract mode (when no menus or images are open), faded images appear to spawn from the center of the table and drift into the edges of the table. Images drift into the sides of the table to hint to users that data is stored "within" the sides of the table. Drifting images cannot be interacted with. Once a user taps on one of the buttons, a menu opens (like Option #1), the animation fades away and the table behaves like Option #1.



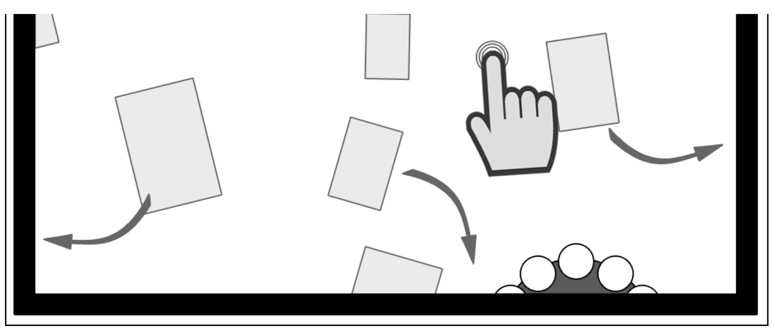
If a user taps anywhere on the table (other than the buttons), a 1-second pop-up of a partial menu will jump out and then back in from the edges of the table. The pop-up appears from one of the length-wise buttons; the edge is determined randomly. Only one pop-up appears at a time. This "hint" was implemented after pilot studies showed that users often interacted with the center of the table first and sometimes did not notice the buttons or border. The pop-up animation was designed with the intention that it would direct the users' attention the buttons or border. Due to the time constraint between the pilot studies and the formal observation studies, the pop-up was only implemented on the length-wise edges of the table



4. **Border + Animation**
The same animation as Option #3 is displayed however is enclosed by the tap-anywhere-border. Once a user taps anywhere on the border, a menu opens (like Option #2), the animation fades away and the table behaves like Option #2.

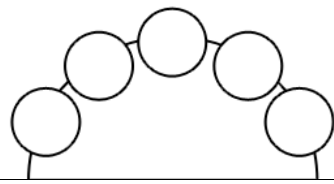
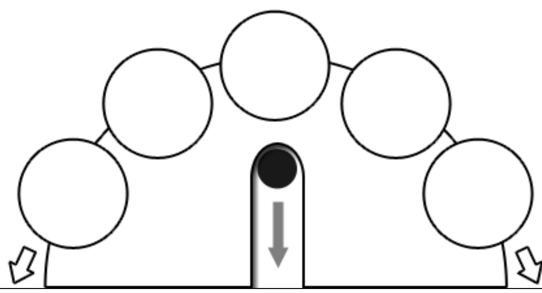
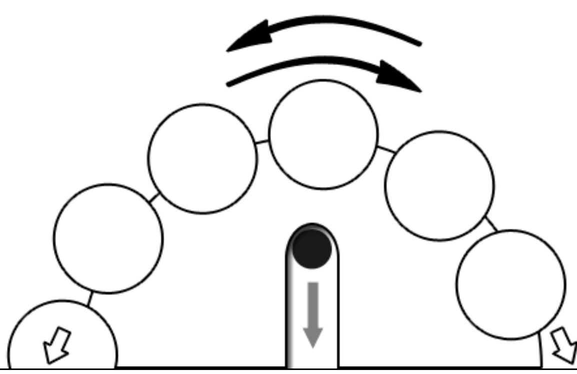


Similar to Option #3, if a user taps anywhere on the table (except for the border), a 1-second pop-up of a partial menu will jump out and then back in from the edges of the table. The pop-up appears along one of the length-wise edges of the tables at the ¼, ½, or ¾ lengths of the table. As previously mentioned, these restrictions to where the pop-up appears were implemented due to the time constraint for the addition of the pop-up animation.



A.2 Crescent Menu Design

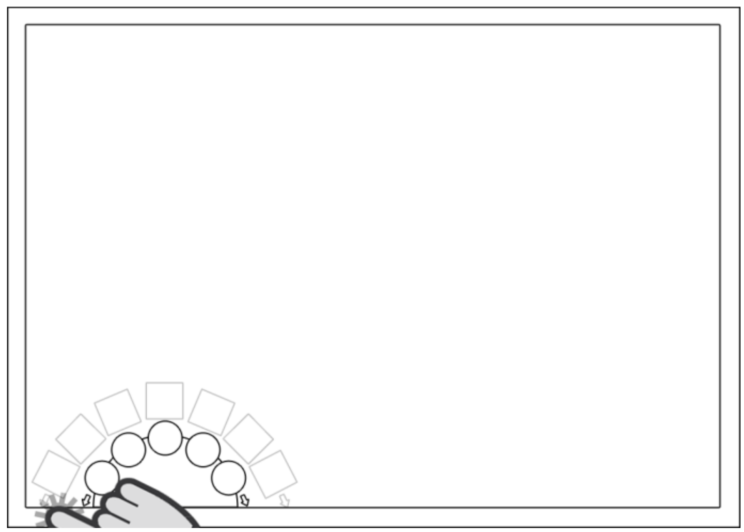
All invocation designs lead to the following menu design:

Opening the Menu	
	1. The crescent expands from touch point/button, revealing Level 1 items/categories.
	2. Level 1/Categories are shown.
	3. Level 1 items rotate slightly to the right and then back to the original placement as a “shake” animation. This acts as a hint to users that the items can be scrolled through.

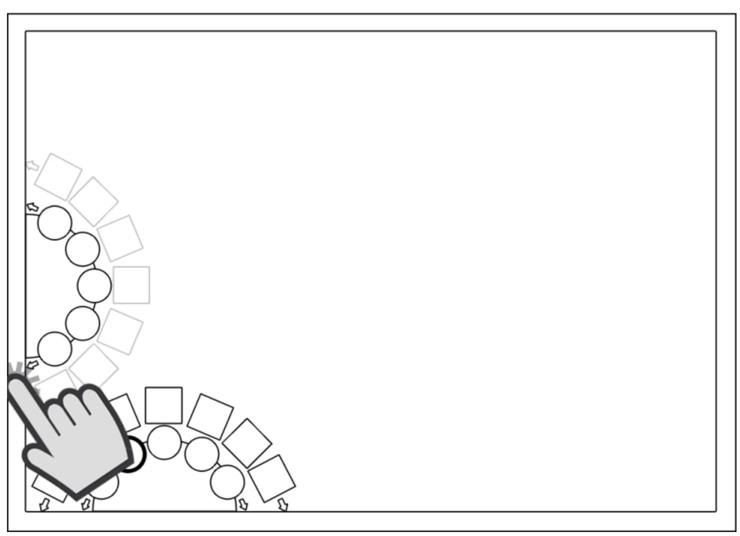
NOTES AND EXCEPTIONS:

- Only one (1) menu per edge of the table (max. 4) can be opened at the same time.

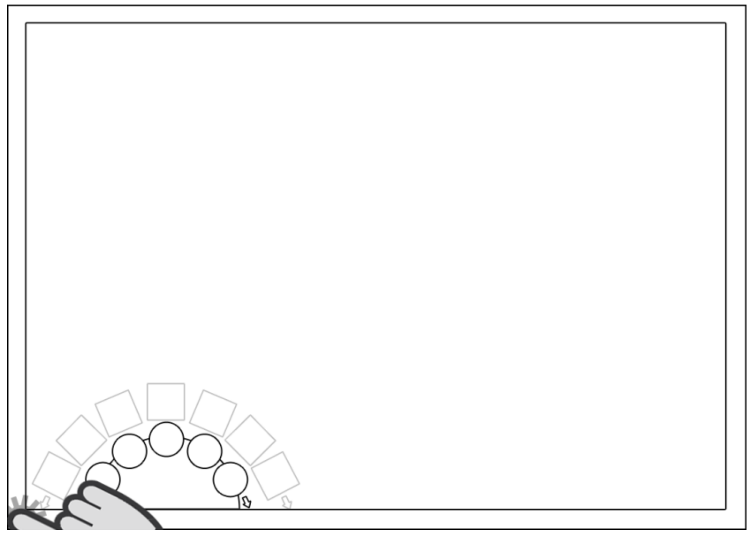
- With the border invocation designs (options #2 and #4), the menu automatically adjusts/shifts for corner/edge cases:
    - *Edge Case:* If a user taps on the border near a corner, the menu will not open horizontally-centered to the tapped spot. Instead, it will automatically open in a shifted position such that it is in the closest possible position to the tapped spot without being cut off by the edges of the table (accounting for having level 2 open as well).



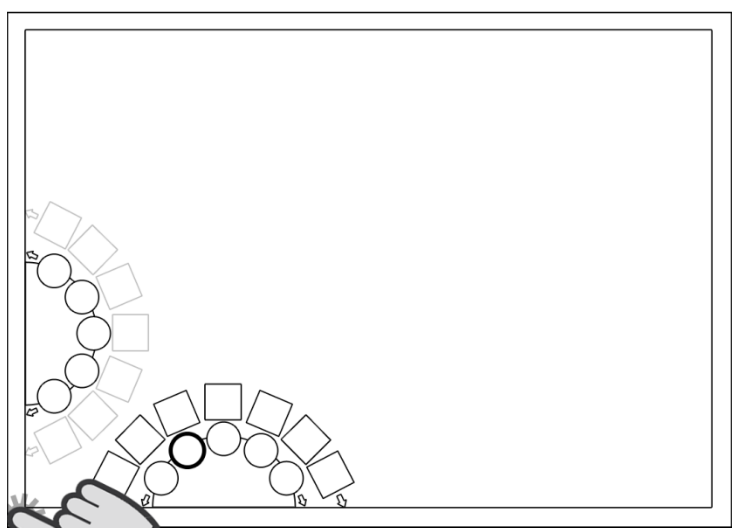
- *Edge Case + Other Adjacent User:* If a user taps on the border near a corner and there is a menu already open on an adjacent edge, the menu will open in a shifted position such that it is in the closest possible position to the tapped spot without being cut off by the edges of the table and without obstructing the menu that is already open (accounting for having level 2 open as well).

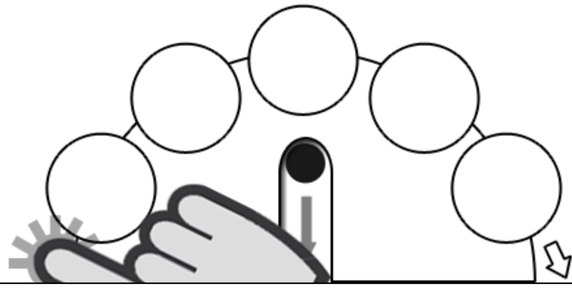
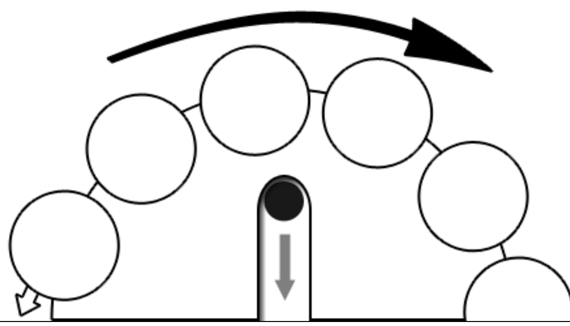
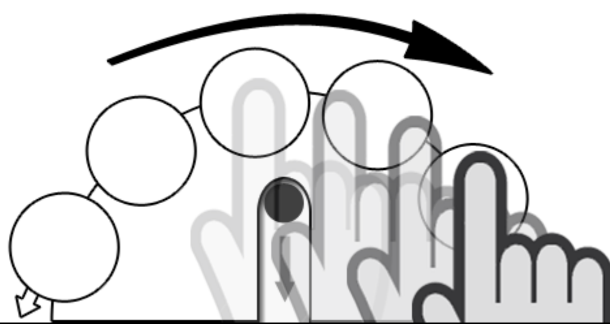


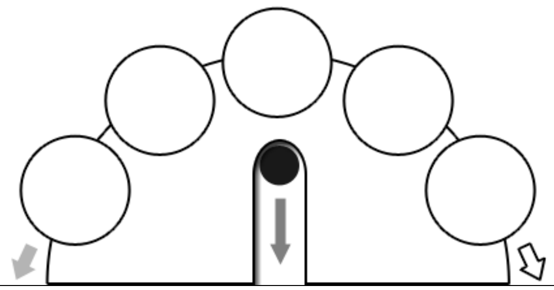
- *Corner Case:* If a user taps the corner of the table (in the border), the menu will invoke to the right (or clockwise) of the touch point. Similar to the *Edge Case*, the menu will automatically open shifted to a position such that it is in the closest possible position to the tapped spot without being cut off by the edges of the table (accounting for having level 2 open as well).



- *Corner + Other Adjacent User:* If a user taps the corner of the table (in the border) and there is a menu already open on an adjacent edge, the menu will open on the unoccupied adjacent edge. The menu will open automatically shifted to a position such that it is in the closest possible position to the tapped spot without being cut off by the edges of the table and without obstructing the menu that is already open (accounting for having level 2 open as well).



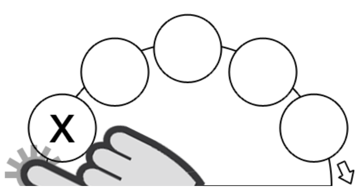
Navigating within a Level	
	1. User taps the arrow button to browse within a level.
	2. All items in the selected level rotate in the opposite direction of the selected direction to show more items. For example, tapping the left arrow will cause the items to rotate to the right, so that items to the left are revealed (similar to scroll bar behaviour). Items will rotate to reveal a new “set” of items; e.g. at level 1, 5 new items will rotate into view, and at level 2, 7 new items will rotate into view.
	3. Users can also swipe/drag a level to navigate through it. Items rotate in the direction of the swipe/drag. Items will only rotate as far as they are dragged (e.g. in the figure to the left, items are rotated 3 items to the right).

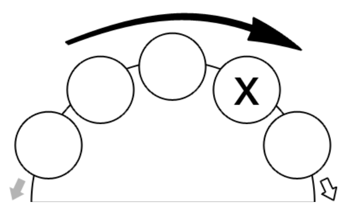
	4. When the end of a level (no more content to scroll to) has been reached, the corresponding arrow is grayed-out and disabled. If a user tries to rotate via the drag gesture, will rotate slightly to reveal there is nothing after the last item and then automatically bounce back to the last item (similar to the iPhone or iPad scrolling interaction).

NOTES AND EXCEPTIONS:

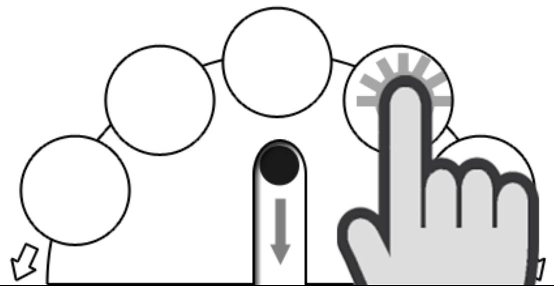
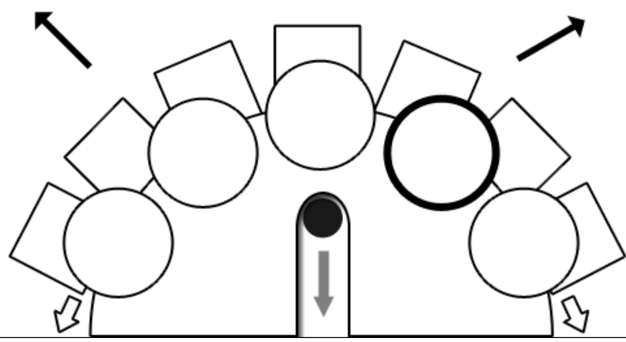
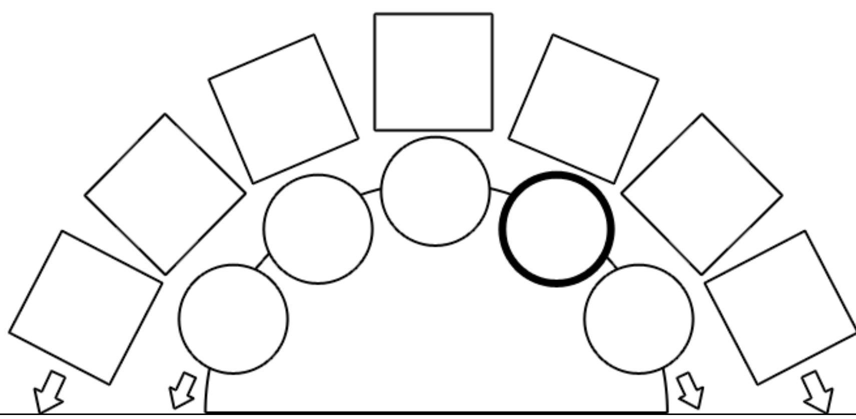
- Browsing in all levels uses the same interaction methods. Regardless of how many levels are open, each level can be independently browsed.

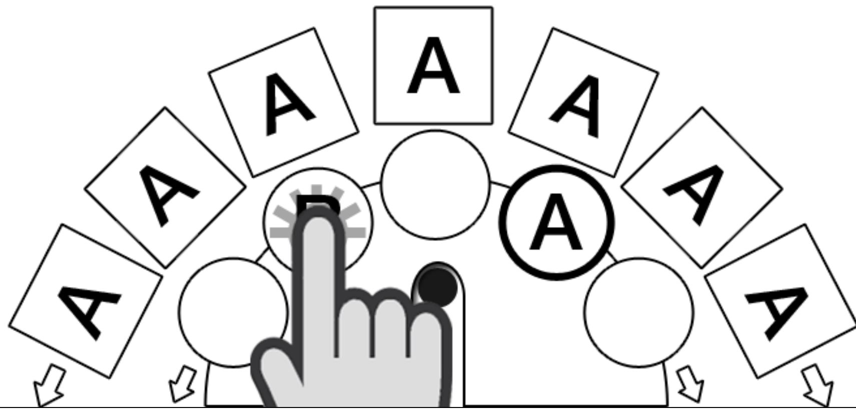
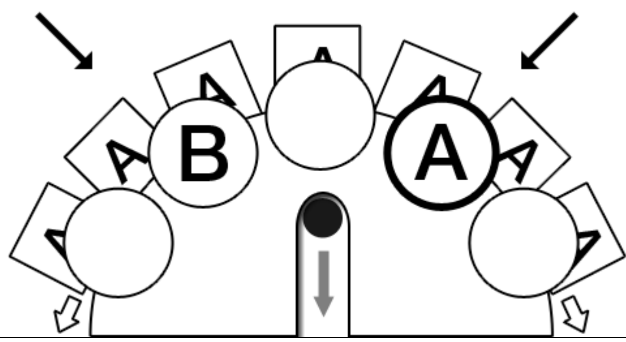
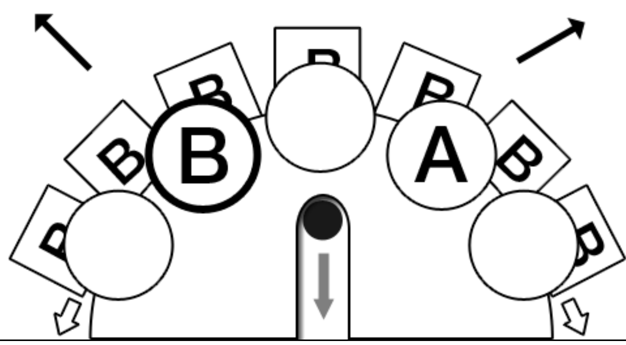
- If there is not a “full set” of items to be rotated into view, items will only rotate far enough to reveal the last item on that side. For example, if a user taps the left arrow and there are only 3 items in the left set to rotate into view, items will only rotate 3 items to the right and the left arrow will then appear grayed-out.

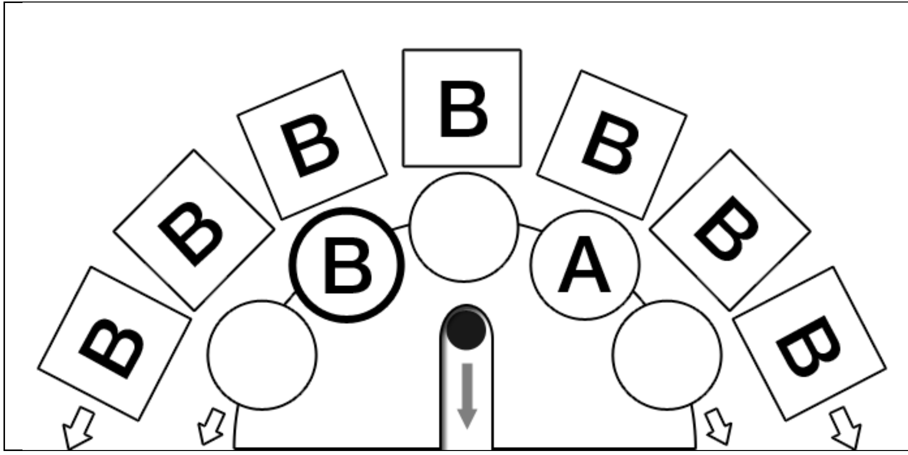


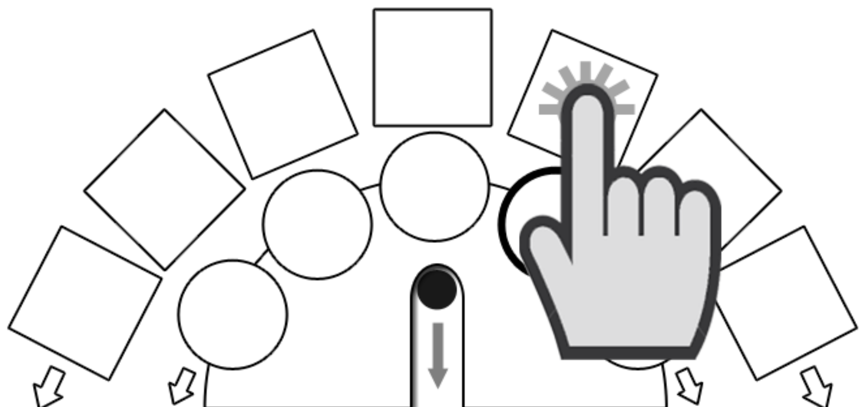
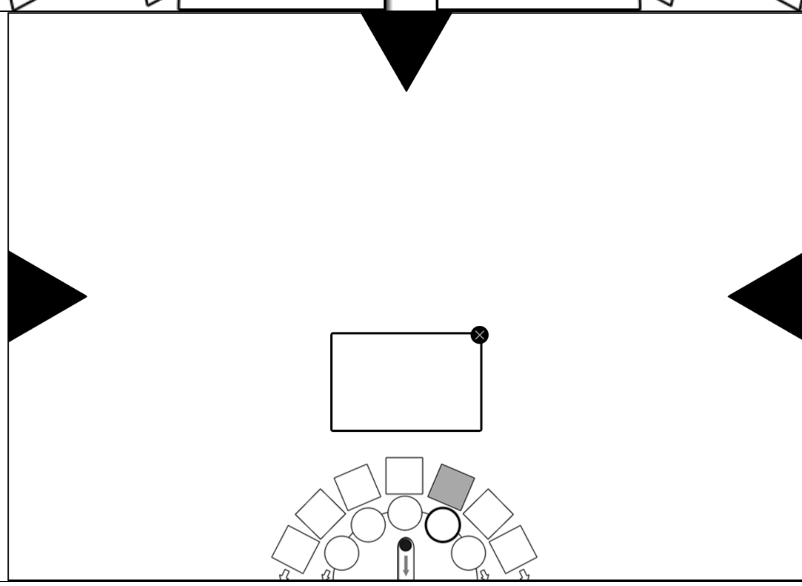
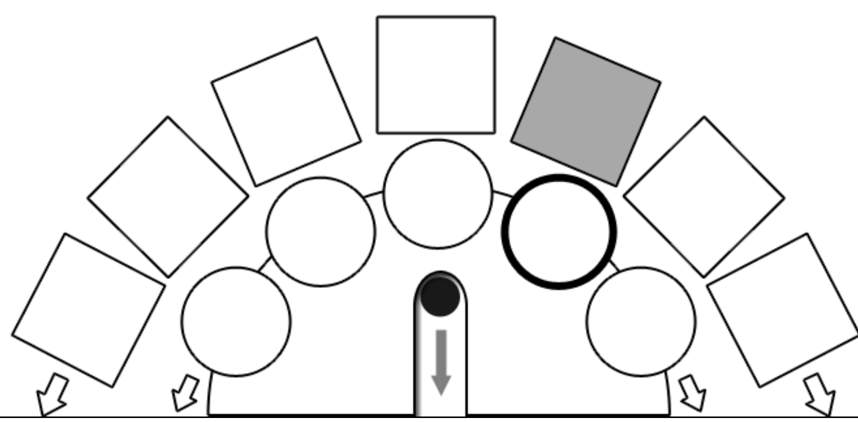


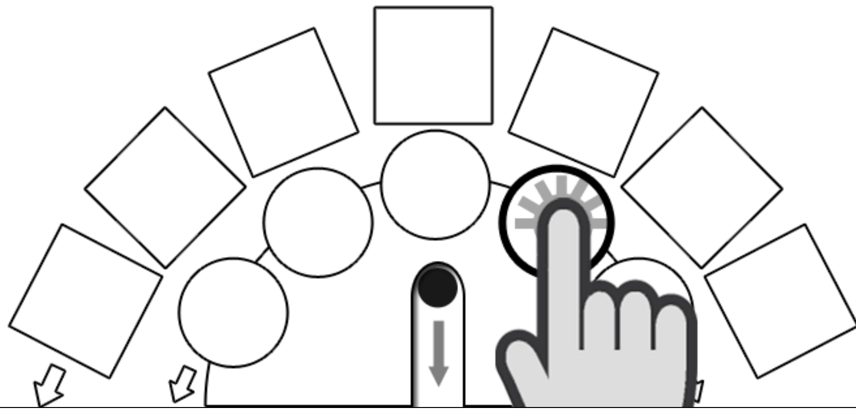
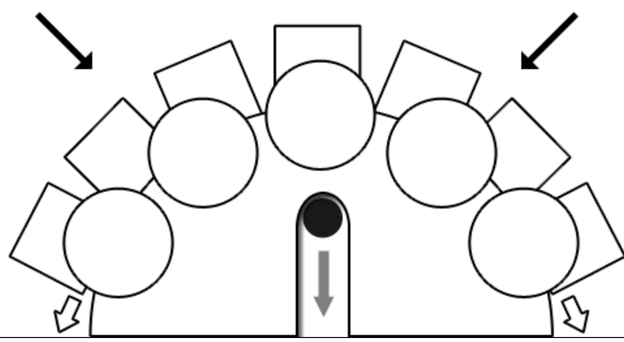
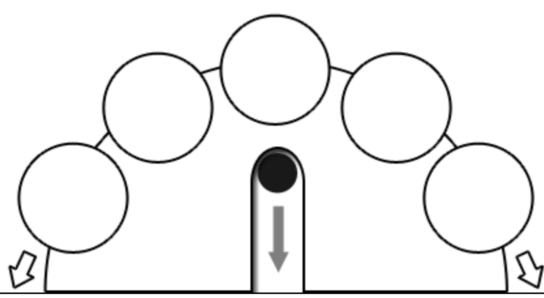
- To avoid accidental selections when scrolling via drag gesture, selections are only confirmed on the touch-up event. For example, when a user touches an item in the menu, the corresponding action (e.g. opening another menu level or opening an image) will only occur when the user lifts his/her finger.

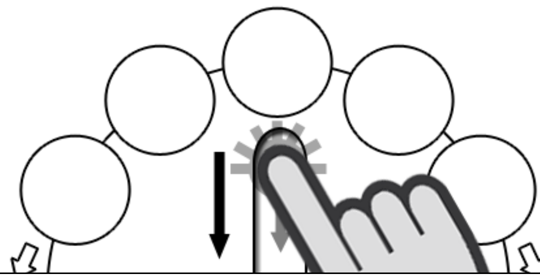
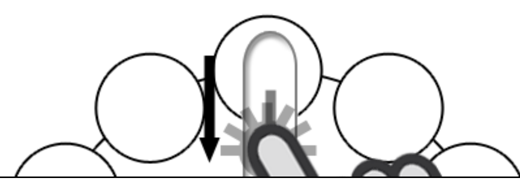
Selecting a Category/Opening Level 2	
	1. User selects a category.
	2. Selected category remains in selected state. Level 2 items of the selected category expand into view around the crescent.
	3. Level 2 items are shown.

Changing Categories	
	1. If a category is already selected (Level 2 items displayed), a user can change categories by tapping a different category.
	2. Level 2 minimizes into the crescent.
	3. Level 2 expands from the crescent displaying items for the newly selected category. (The total animation time for both minimizing and expanding should be relatively fast, ~1 second).

	4. Level 2 items are shown and only the newly selected category remains in the selected state.

Selecting an Item	
	1. User selects an item (image/video).
	2. The selected image opens directed towards the edge of the table from which it was selected and centered to the menu it was selected from. Once opened, items are rotatable, translatable, and resizable. Several items can be open at the same time. Tapping on an open item brings it to the front (top layer)). Tapping on the ‘x’ icon on an open item closes it.
	3. If an item is open on the table, it appears grayed-out in the menu.

Closing Level 2	
	1. Selecting the already-selected level 1 category closes level 2 and brings the user back to the level 1 categories.
	2. Level 2 minimizes into the crescent.
	3. Only Level 1 categories are shown.

Closing the Menu	
	1. A draggable button in a notch is constantly displayed in the center of the crescent. As a user starts to drag the button downwards, the entire menu also starts to slide into the edge of table (close).
	2. The button must be dragged completely to the edge of the table to confirm the closing action. The image of the notch fades slightly as the user approaches the edge. If the user releases the button before completing the dragging motion (to the edge of the table), the entire menu will slide back up into its original position. Otherwise, the menu will slide downwards, completely into the edge of the table. The respective edge of the table will return to the original invocation state.

NOTES AND EXCEPTIONS:

- If a menu is inactive for 1 minute, the entire menu will glow for 2 seconds and then automatically start to close by slowly sliding into the edge of the table (sliding animation time ~3 seconds). This timeout feature is cancelled if a user taps anywhere on the menu before it completely closes.
- If no menus are open, any open content on the table will automatically close after 10 seconds of inactivity.

Appendix B
Study Material

B.1 Posted Informed Consent Sign

UNIVERSITY OF WATERLOO

ATTENTION!

Research Study in Progress

Activity at this table is being observed and video recorded.

By participating in this tabletop activity, you are consenting to be observed and video recorded.

You may withdraw your participation at any time.

Further information can be obtained from the *Information and Feedback sheet for Participants* (from the Researcher). If you have any questions, please ask the researcher, Mindy Seto.

Your participation in the tabletop activities implies that you voluntarily agree to be video recorded for use in a research project to evaluate interface elements for digital tabletop displays. Your participation in the research activities signifies that you voluntarily agree to participate in the project.

Your performance in this study will be kept strictly confidential. All information you provide is considered completely confidential. The video recording is from above. If any clear facial images appear in recordings, and may be used in publications or presentations, the facial image will be blurred. Data and video recordings collected during this observation study will be retained for two years in a secure area in the Department of Engineering to which only authorized researchers involved with this study will have access. There are no known or anticipated risks associated with participation in this study.

This study has been reviewed and received ethics clearance through the Office of Research Ethics at the University of Waterloo. However, the final decision about participation is yours. If you have any comments or concerns resulting from your participation in this study, please contact Dr. Susan Sykes at the Office of Research Ethics at (519) 888-4567 ext. 36005 or ssykes@uwaterloo.ca.

B.2 Information Letter for Participants

Dear Participant,

Thank you for your participation in this study. The purpose of this study is to observe how people interact with the digital tabletops in public settings.

The data collected during this study will contribute to a better understanding of how people interact with digital tabletops and how touch interaction and interface design can be improved.

No personal or identifying information was collected during your participation. Please remember that any data pertaining to you as an individual participant will be kept confidential. Once all the data, such as video recordings, are collected and analyzed for this project, we plan on sharing this information with the research community through my thesis. If any clear facial images appear in recordings, and are used in publications or presentations, the facial images will be blurred. If you are interested in receiving more information regarding the results of this study, or if you have any questions or concerns, please contact us at the email addresses listed at the bottom of the page. If you would like a summary of the results, please let us know now by providing us with your email address. When the study is completed, we will send it to you. The study is expected to be completed by December 2011.

As with all University of Waterloo projects involving human participants, this project was reviewed by, and received ethics clearance through, the Office of Research Ethics at the University of Waterloo. Should you have any comments or concerns resulting from your participation in this study, please contact Dr. Susan Sykes in the Office of Research Ethics at 519-888-4567, ext., 36005, or at ssykes@uwaterloo.ca.

Thank you again,

Amanda Mindy Seto
Graduate Student
University of Waterloo
amkseto@uwaterloo.ca

Stacey Scott
Professor
University of Waterloo
s9scott@uwaterloo.ca

Mark Hancock
Professor
University of Waterloo
m2hancoc@uwaterloo.ca

B.3 Posted Exhibit Sign

Appendix C

Coding Scheme

The following table outlines the complete coding scheme used to analyze each study group.

Category	Code	Description	Source
User Demographic	Adult	User appears to be over the age of 18 (often guardian to accompanying children)	Field notes, Video
	Adolescent	User appears to be between the age of 13 and 18	Field notes, Video
	Child	User appears to be under the age of 13	Field notes, Video
	Interacter	User makes contact with the interactive surface of the table at least once	Video, Log files
	Observer	User only watches activity on the table; does not interact with interactive surface of the table. User appears in camera view.	Video
	First-Time Use	User has not previously interacted with the table	Field notes
	Repeat User	User has interacted with the table more than once within the total observational (4-day) period	Field notes
Initial Interaction States	Notice	User's focus of attention is on table / show indication that they notice the table/signage (i.e. by looking at the table or reading the sign)	Field notes
	Approach	User physically approaches the table	Field notes, Video
	Interact	User touches the table	Field notes, Video, Log files
Table Start State	Previous menu(s) open	On approach to the table, at least one menu was already open	Field notes, Video, Log files
	Previous content open	On approach to the table, at least one item (content) from the menu was already open	Field notes, Video, Log files

Category	Code	Description	Source
Exploratory Interaction	1st touch on floating images	User's 1st touch was on floating images	Video
	1st touch on open space	User's 1st touch was on center/open space of table	Video
	1st touch on invocation element	User's 1st touch was on an invocation element	Video, Log files
	Interact with pop-up	User interacts with (i.e. taps or tries to tap) the pop-up animation	Field notes, Video
	Interact with floating images	User interacts with (i.e. tries to tap or drag) the floating images	Field notes, Video
	1st touch full hand	User taps on table with an open hand (i.e. 5 fingers extended), or two opens hands	Video
	1st touch single finger	User taps on table with a single finger	Video
	Explore touch	Number of touches before menu invocation (approximation)	Video, Log Files
	Look around physical table	User(s) look around physical table for physical buttons	Video
Menu Invocation	Invoke menu at pop-up	User opens menu at the location of the pop-up animation	Field notes, Video, Log files
	Intentional menu invocation	User opens a menu on the table by a purposeful interaction when the user's focus of attention was on the invocation of element being interacted with	Field notes, Video, Log files
	Unintentional menu invocation	User accidently opens a menu on the table when the user's focus of attention was not on the invocation element	Field notes, Video, Log files
	Unintentional menu invocation by lean & use menu	User unintentionally opens a menu from leaning on the table and interacts with the open menu	Video, Log files
	Unintentional menu invocation by other interaction & use menu	User unintentionally opens a menu from an interaction intended for another item and interacts with the open menu	Video, Log files
	Unintentional menu invocation by lean & close menu	User unintentionally opens a menu from leaning on the table and immediately closes the menu	Video, Log files

Category	Code	Description	Source
Menu Invocation (cont.)	Unintentional menu invocation by other interaction & close menu	User unintentionally opens a menu from an interaction intended for another item and immediately closes the menu	Video, Log files
	Drag menu to open	User tries to drag the menu out of the border/button	Video
	Menus opened	Number of new menus opened (within a group)	Video, Log files
Menu Interaction	Items opened	Number of items the user(s) successfully opens from menu	Log files
	Drag to scroll	User successfully drags finger to scroll through menu	Video
	Drag item to open	User tries to drag item from menu (to open item)	Video
	Close menu	User successfully closes menu	Video, Log files
General Interaction	Technical error	Correct user interaction, however no response from system/table	Field notes, Video, Log files
	Try to control motion wall	User interacts with table assuming it controls the motion wall	Field notes, Video
	Learning by observing	A user learns how to invoke a menu by observing interactions of other users within the same group.	Video
	Learning by instruction	A user explicitly verbally (or by demonstration) teaches other users within the same group how to invoke a menu	Video
	Session length	The total interaction time of a group from when they approach to when they leave the table and camera view.	Video, Log files

For the scope of this research, not all codes were investigated in detail in the data analysis, outlined in Section 4.7. In the “User Demographics” code category, the distinction between a “First-Time User” and “Repeat User” were omitted as it was not possible to accurately distinguish this user classification from the collected data. In the “Exploratory Interaction” code category, the number of “Explore Touches” could not be accurately counted due to the technical limitations of the hardware (i.e. not all touches were logged) and visual obstructions in the video data (e.g. the head of a participant temporarily blocking camera view). In the “Menu Invocation” code category, the different types of unintentional menu invocations were grouped in the “Unintentional Menu Invocation” code. All “Menu Interaction” codes were not included in the statistical data analysis because they were beyond the scope of menu invocation. These codes did, however, contribute to the menu recommendations presented in Section 6.2.2. In the “General Interaction” code category, “Learning by observing” and “Learning by instruction” were not analyzed because without participant interviews and control groups, it was difficult to accurately assess learning effects.

Appendix D
Statistical Calculations

D.1 Statistical Analysis of Explore Time

Between-Subject Factors

		Value Label	N
Animation	1.00	Animation	8
	2.00	No Animation	8
InvocationType	1.00	Border	8
	2.00	Buttons	8

Descriptive Statistics

Animation	InvocationType	Mean	Std. Deviation	N
Animation	Border	11.250	4.031	4
	Buttons	10.250	3.775	4
	Total	10.750	3.65474	8
No Animation	Border	12.250	6.946	4
	Buttons	10.250	2.630	4
	Total	11.250	4.979	8
Total	Border	11.750	5.285	8
	Buttons	10.250	3.012	8
	Total	11.000	4.227	16

Two-Way ANOVA (Test of Between-Subjects Effects)

Source	df	Mean Square	F	Sig.	Partial Eta Squared
Animation	1	1.000	.047	.833	.004
InvocationType	1	9.000	.420	.529	.034
Animation * InvocationType	1	1.000	.047	.833	.004
Error	12	21.417			

D.2 Statistical Analysis of Percentage of Interactions with Animations

Descriptive Statistics

	InvocationType	N	Mean	Std. Deviation	Std. Error Mean
Interact_w_PO	Border	4	30.000	13.540	6.770
	Buttons	4	56.250	13.793	6.896
OpenMenuPO	Border	4	87.500	25.000	12.500
	Buttons	4	29.168	47.871	23.936
Interact_flt_img	Border	4	44.375	37.770	18.885
	Buttons	4	54.503	11.833	5.917

Independent Samples t-test

	t-test for Equality of Means				
	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
Interact_w_PO*	-2.716	6	.035	-26.250	9.664
OpenMenuPO*	2.160	6	.074	58.333	27.003
Interact_flt_img*	-.512	6	.627	-10.128	19.790

*equal variances assumed

PO = pop-up animation

flt_img = floating images animation

D.3 Statistical Analysis of Percentage of First Touches on Invocation Elements

Between-Subject Factors

		Value Label	N
Animation	1.00	Animation	8
	2.00	No Animation	8
InvocationType	1.00	Border	8
	2.00	Buttons	8

Descriptive Statistics

Animation	InvocationType	Mean	Std. Deviation	N
Animation	Border	2.500	5.000	4
	Buttons	6.440	8.054	4
	Total	4.470	6.554	8
No Animation	Border	3.125	6.250	4
	Buttons	21.590	16.796	4
	Total	12.358	15.332	8
Total	Border	2.813	5.250	8
	Buttons	14.015	14.638	8
	Total	8.414	12.097	16

Two-Way ANOVA (Test of Between-Subjects Effects)

Source	df	Mean Square	F	Sig.	Partial Eta Squared
Animation	1	248.851	2.422	.146	.168
InvocationType	1	501.984	4.885	.047	.289
Animation * InvocationType	1	210.976	2.053	.177	.146
Error	12	102.760			

D.4 Statistical Analysis of Percentage of Menu Invocations

Between-Subject Factors

		Value Label	N
Animation	1.00	Animation	8
	2.00	No Animation	8
InvocationType	1.00	Border	8
	2.00	Buttons	8

Descriptive Statistics

Animation	InvocationType	Mean	Std. Deviation	N
Animation	Border	66.875	19.725	4
	Buttons	54.165	31.551	4
	Total	60.520	25.289	8
No Animation	Border	56.458	24.443	4
	Buttons	39.455	24.128	4
	Total	47.956	24.252	8
Total	Border	61.666	21.303	8
	Buttons	46.810	27.165	8
	Total	54.238	24.799	16

Two-Way ANOVA (Test of Between-Subjects Effects)

Source	df	Mean Square	F	Sig.	Partial Eta Squared
Animation	1	631.391	.985	.341	.076
InvocationType	1	882.833	1.377	.263	.103
Animation * InvocationType	1	18.426	.029	.868	.002
Error	12	641.033			

D.5 Statistical Analysis of Percentage of Intentional Menu Invocations

D.5.1 Two-Way ANOVA

Between-Subject Factors

		Value Label	N
Animation	1.00	Animation	8
	2.00	No Animation	8
InvocationType	1.00	Border	8
	2.00	Buttons	8

Descriptive Statistics

Animation	InvocationType	Mean	Std. Deviation	N
Animation	Border	64.288	27.354	4
	Buttons	100.000	.000	4
	Total	82.144	26.174	8
No Animation	Border	22.915	15.773	4
	Buttons	94.445	11.110	4
	Total	58.680	40.267	8
Total	Border	43.601	30.271	8
	Buttons	97.223	7.856	8
	Total	70.412	34.974	16

Two-Way ANOVA (Test of Between-Subjects Effects)

Source	df	Mean Square	F	Sig.	Partial Eta Squared
Animation	1	2202.190	7.862	.016	.396
InvocationType	1	11500.954	41.058	.000	.774
Animation * InvocationType	1	1282.893	4.580	.054	.276
Error	12	280.113			

D.5.2 Independent Samples t-test (Invocation Type = Border)

Descriptive Statistics

	Animation	N	Mean	Std. Deviation	Std. Error Mean
IntentionalInvocation	Animation	4	64.288	27.354	13.677
	No Animation	4	22.915	15.773	7.887

Independent Samples t-test

	t-test for Equality of Means				
	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
IntentionalInvocation*	2.621	6	.040	41.373	15.788

*equal variances assumed

D.5.3 Independent Samples t-test (Invocation Type = Buttons)

Descriptive Statistics

	Animation	N	Mean	Std. Deviation	Std. Error Mean
IntentionalInvocation	Animation	4	100.000	.000	.000
	No Animation	4	94.445	11.110	5.555

Independent Samples t-test

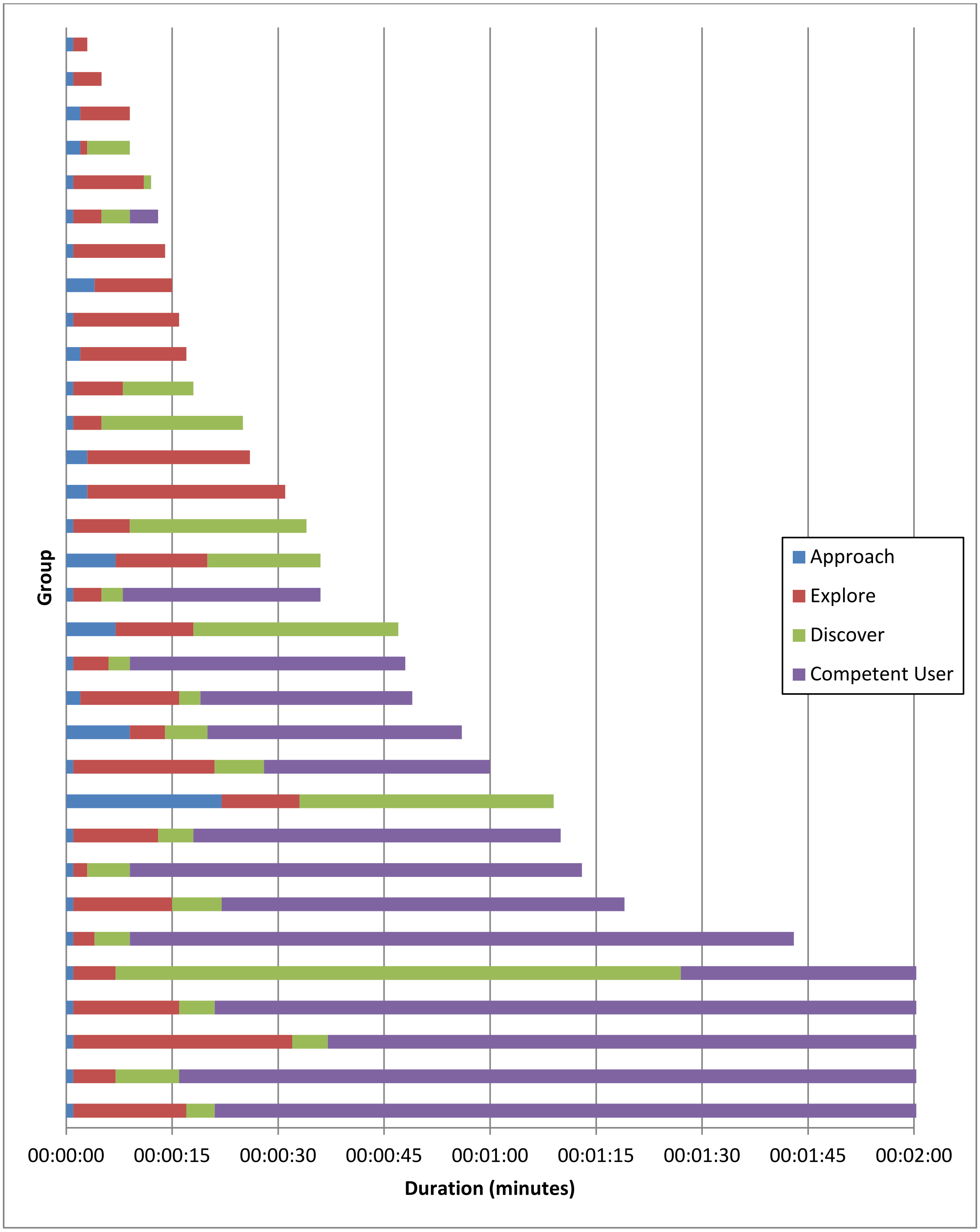
	t-test for Equality of Means				
	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
IntentionalInvocation*	1.000	6	.356	5.555	5.555

*equal variances assumed

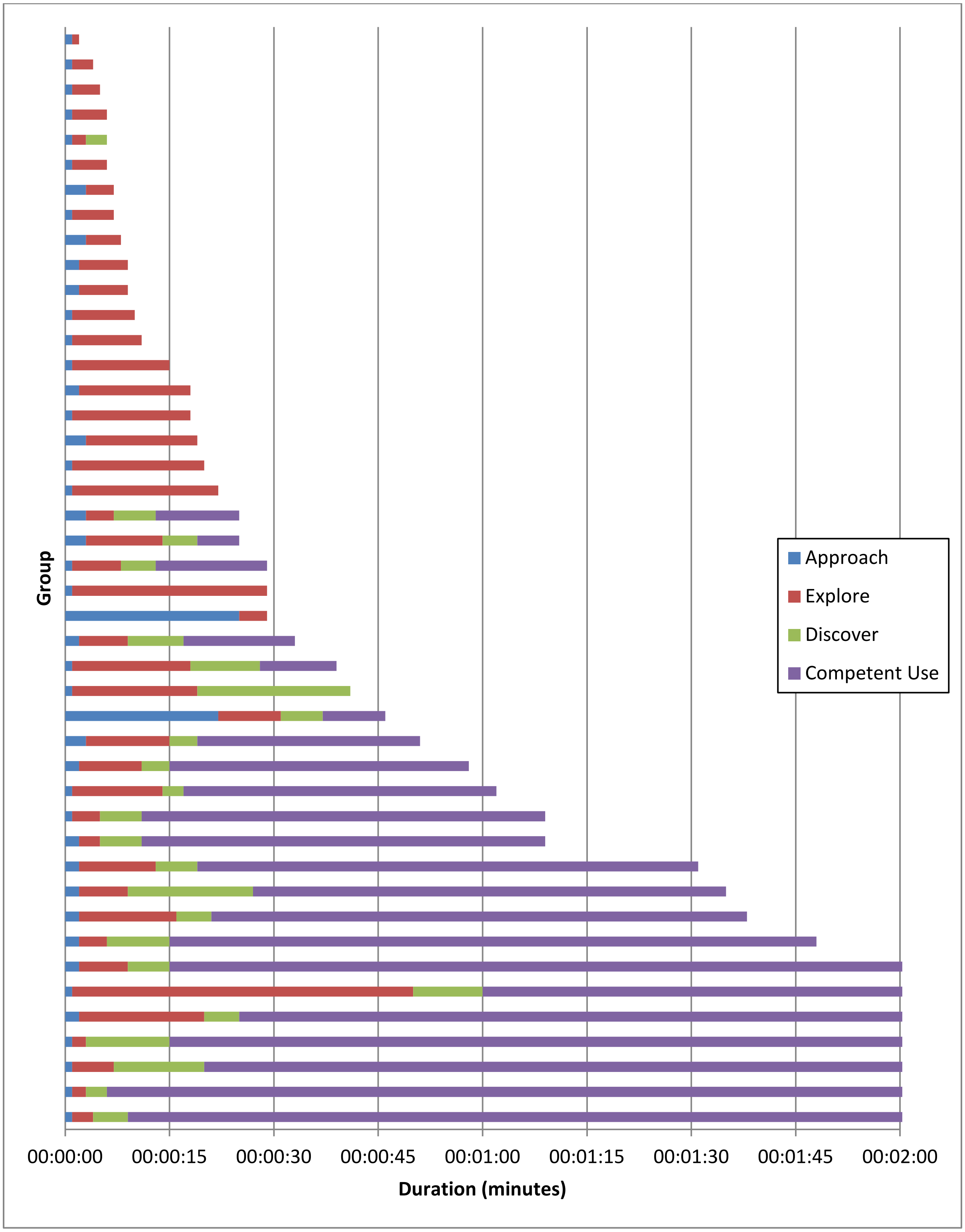
Appendix E
Timeline of User Interaction States

The following are user timelines depicting the interaction states of each user group in each condition. Each bar represents one group. The time axis is set to a maximum of 2 minutes as the duration of Competent Use was not investigated for the scope of this research.

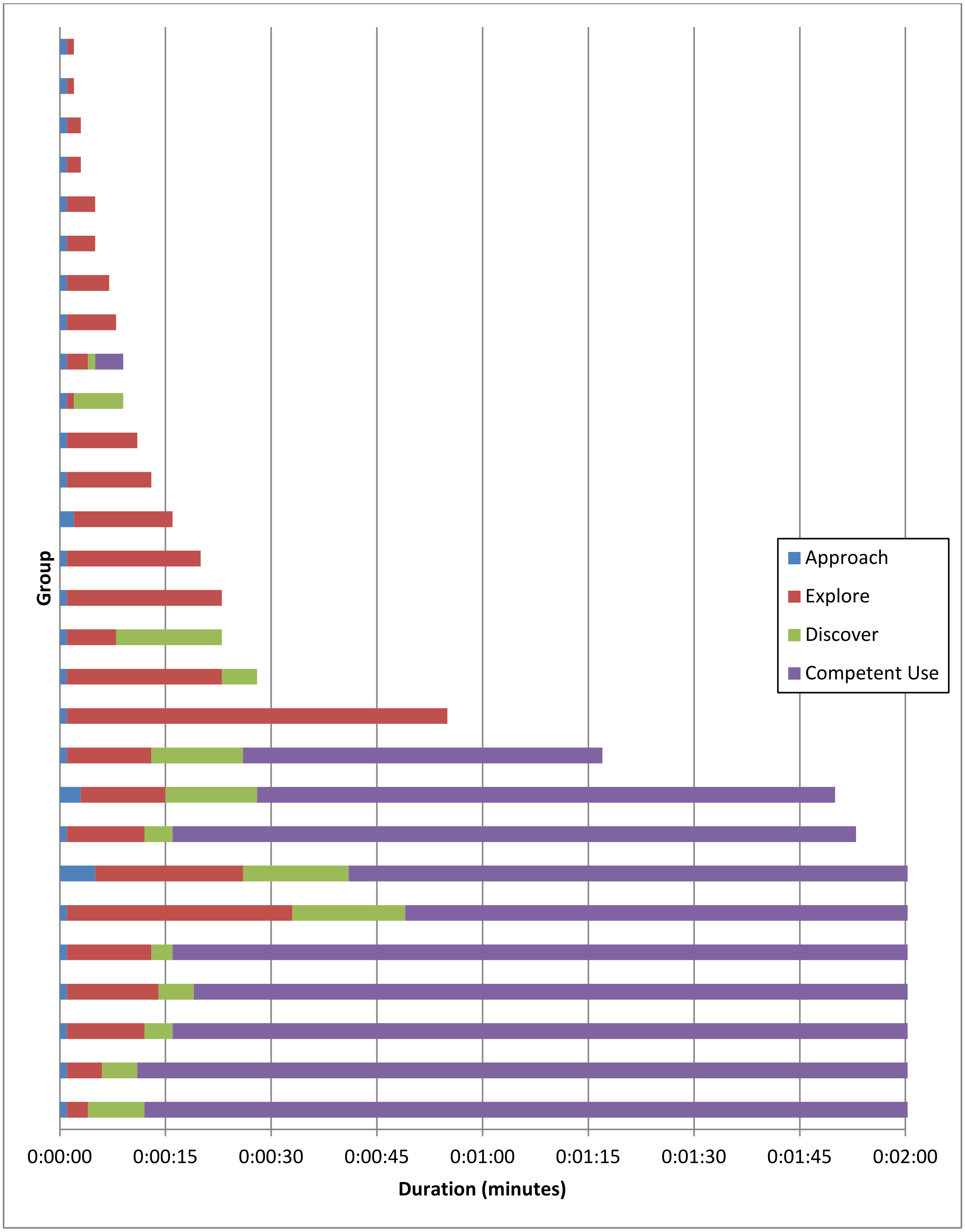
E.1 Border + Animation



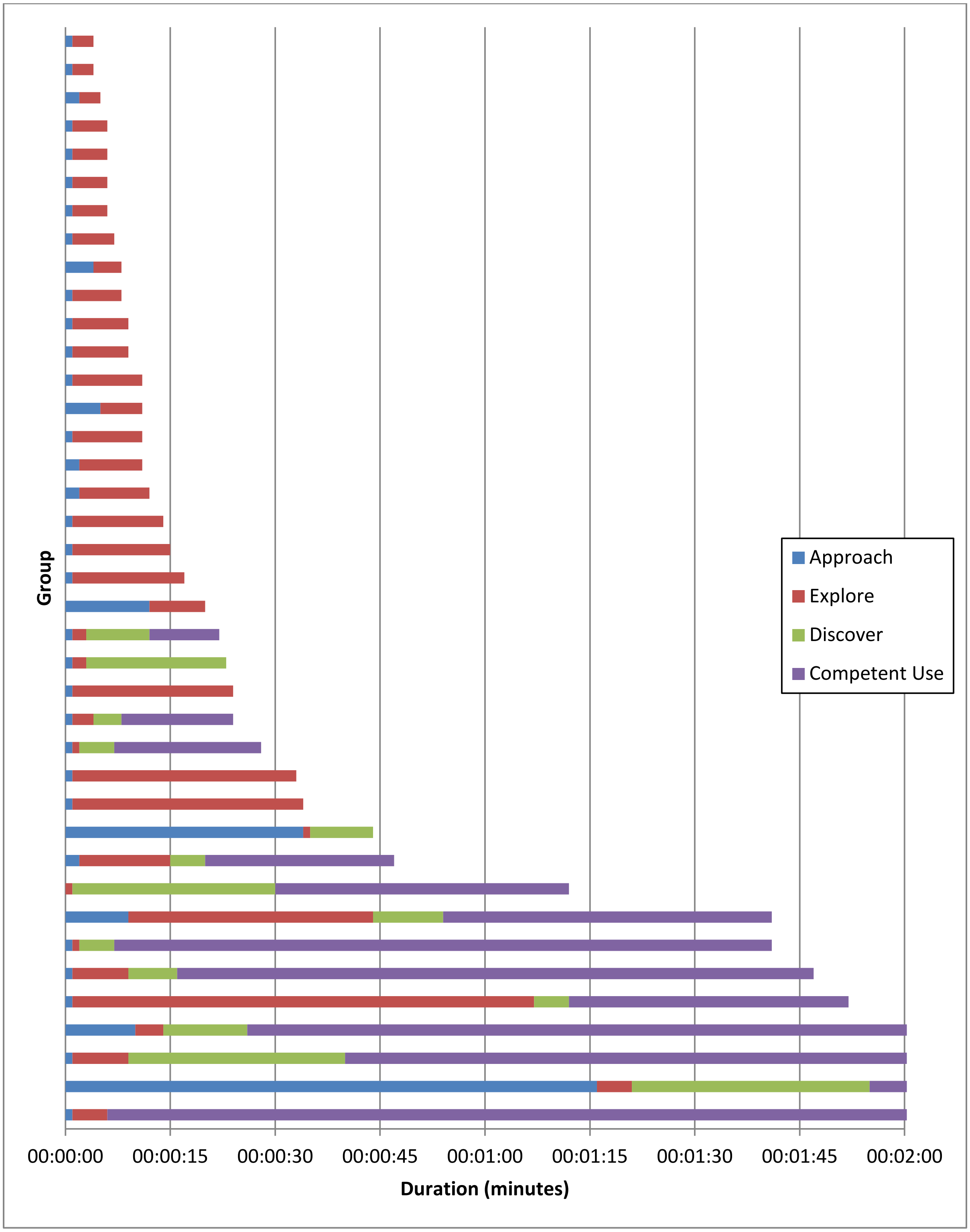
E.2 Buttons + Animation



E.3 Border


Group
Approach
Explore
Discover
Competent Use
0:00:00
0:00:15
0:00:30
0:00:45
0:01:00
0:01:15
0:01:30
0:01:45
0:02:00
Duration (minutes)

E.4 Buttons


Group
Approach
Explore
Discover
Competent Use
00:00:00
00:00:15
00:00:30
00:00:45
00:01:00
00:01:15
00:01:30
00:01:45
00:02:00
Duration (minutes)