Tango Cards:
A Card-Based Design Tool for Informing the Design of Tangible Learning Games

by

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B.Eng., Tongji University, 2006

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Abstract

For over thirty years researchers have suggested that both tangible user interfaces and digital games have potential to support learning. Each domain now has a well-developed body of literature about how to design them to enable learning benefits. What is needed is a way to bring this knowledge, which is often lengthy, dense, and jargon laden to design practice. To address this need, I designed and evaluated Tango Cards—a card-based design tool. I found that Tango Cards enabled a variety of uses that made design knowledge about tangible learning games accessible to designers. I identified and discussed how specific card features supported or limited card use by designers. Drawing on the findings of Tango Cards and previous cards, I set forth design considerations that can support others to create design tools (card-based or alike) that bring scholarly design knowledge to designers.

Keywords: design tool; design cards; tangible user interface; learning; educational games; tangible learning games
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1. Introduction

Interactive technology is rapidly transforming the ways in which people work, play, communicate, and learn. For over forty years, researchers have worked to understand how to harness the motivation power of games to create effective games for learning. There now exists a robust body of knowledge about what makes good educational digital games. For example, Gee (2007b) analyzed the learning principles behind good video games in order to determine what makes them motivating. Fisch (2005) put forward design considerations about how to integrate educational content into game play effectively. de Castell and Jenson (2007) proposed that effective games embed learning material into a broad range of game elements including character selection, art, narrative, programming, goals, game structures and play.

In parallel, researchers investigated how tangible user interfaces (TUIs) may be designed to support learning. For example, they found that the physical manipulation involved in tangible interaction may enable learners to offload elements of mental processes to actions on physical objects, which may make problem solving simpler (Antle, Droumeva & Ha, 2009). The physical properties of tangible objects may be used to represent metaphorically related concepts to help learners understand abstract concepts (Manches & O'Malley, 2012; Zuckerman, Arida & Resnick, 2005). TUIs also may be designed to support collaboration because they may provide multiple objects with which to interact in larger spaces than traditional desktop screen-based systems provide (Hornecker, 2005). In particular, Antle and Wise’s Tangible Learning Design Framework (2013) represents a culmination of a range of findings about designing effective TUIs for learning.

Recently, researchers have brought these two research fields together, proposing that tangible learning games may be a promising approach that can be designed to support many kinds of learning. Design knowledge about educational games (e.g., (Fisch, 2005; Gee, 2007a)), and tangibles for learning (e.g., (Antle & Wise, 2013))
provide rich academic knowledge to draw on. However, these academically oriented
design guidelines and frameworks are lengthy, dense, and jargon-laden, which make
them hard to use in design practice (Hornecker, 2010). Rogers (2004) calls for
mechanisms of knowledge transfer between design theory and practice that are “more
lightweight and accessible” than design guidelines and frameworks.

I designed a card-based design tool, called Tango Cards, to bridge the gap
between scholarly design research about tangible learning games, and the practice of
designing such games. Design tools and methods are a well-established form of
intermediate-level knowledge, with their abstraction level spanning a broad range (Höök
& Löwgren, 2012; Löwgren, 2013). Together with other examples of intermediate-level
knowledge, such as patterns, strong concepts, and heuristics, they serve as alternative
ways to construct knowledge and bring theory to practice (Höök & Löwgren, 2012). In
particular, card-based design tools have been used by a number of researchers to
bridge the gap between scholarly knowledge and design practice (e.g., Bekker & Antle,
2011; Halskov & Dalsgård, 2006; Hornecker, 2010; Lucero & Arrasvuori, 2010). They are
hand-sized and typically contain both text and pictures. Researchers have found design
cards to be effective as knowledge “transfer vehicles” (Rogers, 2004) between theory
and practice.

In this thesis, I present the design and evaluation of Tango Cards. The goal of
Tango Cards is to make scholarly knowledge about tangible learning games accessible
to designers to inform their design practice. I designed a set of cards, conducted expert
reviews, and then revised the cards. I conducted a user study on the revised set using a
combination of observation, interview, and survey methods. The goal was to investigate
how designers used the cards, how card characteristics supported or limited card use,
and to better understand in what situations and for whom the cards were effective.
Through a process of synthesis, reflection, articulation, and abstraction (Höök &
Löwgren, 2012), I present general design considerations that can be used to create
design cards (or other tools) to bridge theory and practice in other design spaces.
1.1. Research Questions

- RQ 1.a: How do designers use Tango Cards in different design activities?
- RQ 1.b: In which design activities do designers find the cards useful?
- RQ 1.c: How do the specific design features of Tango Cards (e.g., presentation, form, content) support or limit such uses?
- RQ 2: Are Tango Cards an effective design tool in making design knowledge about tangible learning games accessible to designers during their design process? In which ways do cards make the knowledge accessible to designers? In which situations and for whom?

Some overlap exists between RQ 1.a and RQ 1.b. Some uses that RQ 1.a examines can map directly to RQ 1.b. On the other hand, these two research questions have different focuses. RQ 1.a investigates micro-level card uses and seeks rich context and details, while RQ 1.b looks at usefulness of the cards in macro-level design activities that roughly map to design phases during a design process.

1.2. Thesis Organization

This thesis consists of seven chapters. In this Introduction chapter you are reading, I set up context for the research and introduce the research questions. In Chapter 2, I provide a critical review of the literature that is related to the key facets of my research: tangibles for learning; learning games; design tools and methods for knowledge transfer; and cards as a design tool. In Chapter 3, I present the design process that I used to create the cards and rationale for important design decisions, as well as the findings of the expert reviews of the cards. In Chapter 4, I justify my choice of research methodology—a form of single-case study, which includes a combination of observation, interview, and survey methods. Research design as well as the validity and reliability of the methodology follow. In Chapter 5, I report the findings of the research, organized by research question. In Chapter 6, I analyze and synthesize the findings of this research and previous card works. I lay out a set of general design considerations that can be used to create design tools (cards or alike) to bring theory to practice for other design spaces. In Chapter 7, I sum up key findings and contributions of this research and suggest directions for future research.
2. Background

The design space of my research deals with two areas: tangibles for learning and games for learning. My research also aggregates and generalizes design knowledge about designing cards as a knowledge transfer vehicle between scholarly design research and design practice (with a focus on informing). Accordingly, another important aspect of my research is design tools that bring theory to practice, in particular card-based design tools. In this review, I begin with the tangibles for learning area. I explain the theoretical grounding for the learning benefits of tangibles. I look at the current research status of designing tangibles to support learning, from the perspectives of research prototypes that have been built, empirical studies that have been conducted, and theory development to date. Next I examine the other half of the design space—learning games using the same dimensions as those for tangibles for learning. Then I briefly introduce the development of tangible learning games. Finally I move to the field of design tools and design cards. I draw a review of previous design cards, comparing their goal, focus, and key findings, and discuss their limitations.

2.1. Tangible Interaction for Learning

The term of Tangible User Interfaces (TUIs) was coined by Ishii and Ulmer of the MIT Media Lab at CHI 97 (Ishii & Ullmer, 1997). Their intention was to bring the rich affordances of the everyday physical world to human-computer interaction in order to bridge the gap between the digital world of bits and the physical world of atoms. For example, they developed Tangible Geospace (Figure 2.1), one of the earliest TUI prototypes on their metaDESK platform (Ishii & Ullmer, 1997). Tangible Geospace allows users to explore and manipulate 2D and 3D maps of the MIT campus using miniature MIT landmarks as phicons (physical icons) and an arm-mounted “active LENS” (a physical screen that embodies the window metaphor).
Figure 2.1. *metaDESK*
From “Figure 10 Tangible Geospace on metaDESK,” in (Ishii & Ullmer, 1997).

About the same time as the seminal paper by Ishii and Ullmer, Resnick (1998) and his colleagues—another group of researchers at the MIT Media Lab arrived at a more specific type of TUI that they named *Digital Manipulatives*. Digital Manipulatives are computationally augmented versions of traditional children’s toys such as blocks, beads, and balls. Resnick et al. designed them as a solution for their educational concept of “lifelong kindergarten” (Resnick, 1998). The idea of “lifelong kindergarten” is to enable children to continue enjoying the benefit of learning through physical manipulation as they grow and learn more advanced concepts (such as dynamic systems), which are very difficult to demonstrate and explore through traditional physical objects.

Shaer and Hornecker (2010) define TUIs as “Interfaces that are concerned with providing tangible representations to digital information and controls, allowing users to quite literally grasp data with their hand and effect functionality by physical manipulations of these representations”. A broader definition of TUIs includes aspects of embodied interaction and full-body interaction (Hornecker & Buur, 2006). The TUIs discussed in this thesis are generally in accordance with Shaer and Hornecker’s definition, but also touch on the broader scope in some instances.
2.1.1. Theoretical Groundings

Researchers have suggested many learning benefits of TUIs based on multiple perspectives on cognition and learning theories. Learning through the senses and physical manipulation has a long tradition of practice in kindergarten education. This approach has been claimed effective since the works of two pioneers – Friedrich Froebel (Forrester, 1976) and Maria Montessori (Montessori & Costelloe, 1972). The educational philosophy of constructivism further advocates the approach of learning through hands-on practice with physical objects. Jean Piaget (2013), a pioneer of the constructivist educational theory, argued that knowledge could not be "transmitted" or "conveyed ready made" to another person. What really happens is that the receivers of the knowledge reconstruct their own version of the knowledge. Building on that, Papert (1994) developed his constructionism theory. He claimed that to optimize the reconstruction of knowledge in the mind, education should support learners to construct the idea "in the world" by building products that can be "shown, discussed, examined, probed, and admired". In particular, the value of learning abstract concepts through concrete representations has been recognized by many constructivist researchers. For example, Turkle and Papert (1992) called for a “revaluation of the concrete” in their renowned paper. Papert (1994) contended that concrete thinking was not just a stepping-stone to abstract thinking. Nor was it limited to underdeveloped children. Rather, concrete thinking should be supported and encouraged throughout a person's lifetime. Papert criticized the image of scientific thinking presented by science education, which neglected the role of concrete thinking and did not truly reflect the real scientific thinking process. He thought the real scientific thinking process was more concrete, contextual, and impromptu, in which concrete thinking played a significant role. Ackermann (1996) put forward another important constructivist notion. Iteratively switching between immersing in the learning domain and stepping back to look at it from a distance (“diving-in” and “stepping-out”) is important to achieve deep understanding.

TUIs answer these calls well. TUIs enable people to learn through hands-on practice and physical manipulation. TUIs support people to leverage their knowledge with the real world to lower the threshold of learning to use the interface. With its computational augmentation, TUIs can support teaching complex and abstract concepts.
that are difficult to get across using traditional physical objects. They can help children explore these concepts that were considered too difficult for their age if taught through traditional tools and methods (such as abstract formulas) (Resnick, 1998; Zuckerman et al., 2005). Moreover, by capitalizing on the rich ways of coupling physical input with digital responses, especially in interesting and unexpected ways, TUIs can be used to promote reflection, pique curiosity, encourage exploration, and facilitate playful learning and collaboration (Price, Falcão, Sheridan & Roussos, 2009; Rogers, Scaife, Gabrielli, Smith & Harris, 2002). Studies also show that TUIs can be designed to support collaboration by providing shared space in which people can monitor each other’s actions and gazes (Fernaeus & Tholander, 2006). The physical artefacts of TUIs can serve as referential anchors (verbal or gestural) during the collaboration (Hornecker, 2005).

2.1.2. Examples of Tangible Learning Systems

Researchers have developed many tangible systems over the years to explore the potential of tangibles in support learning. Lego Mindstorms developed by Papert et al. is a pioneering work grounded in the constructionism educational philosophy (Papert, 1993). Mindstorms enable children to program robots on a computer and build customizable robots. Following Papert’s steps, Resnick (1998) and his colleagues designed a community of Digital Manipulatives—computationally augmented physical objects; such as Programmable Bricks (Figure 2.2), BitBalls, and Digital Beads. Digital Manipulatives aim to encourage children to construct knowledge through design projects by leveraging the joint power of computational media and physical manipulation. Zuckerman et al. (2005) developed FlowBlocks (Figure 2.3) and SystemBlocks, two types of Digital Montessori-inspired Manipulatives (DMiMs), to support learning abstract, dynamic behaviours through hands-on modeling and simulation. Raffle, Parkes and Ishii (2004) built Backpacks (Figure 2.4) and Topobo to enable children to investigate basic kinematic principles by designing and constructing robots and manipulating the motion parameters of the robot with tangible handles. Blikstein (2010) made Bifocal Models (Figure 2.5), which connect a computer model to a sensor-based physical model, to support students to develop and investigate scientific inquires.
Figure 2.2. Dancing creatures built with Crickets
From “Figure 3: Dancing creatures, with communicating Crickets,” in (Resnick, 1998).

Figure 2.3. FlowBlocks
From “Figure 1: A 'normal distribution' simulation,” in (Zuckerman et al., 2005).

Figure 2.4. Backpacks
From “Figure 5. Distributed Time Delay leads to waves (left) and a walking caterpillar (right),” in (Raffle et al., 2004).

Figure 2.5. Bifocal Model
From “Figure 3” in (Blikstein, 2012).

Figure 2.6. Kurio
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Some other tangible systems explored learning through social interaction and collaboration. For example, Kurio (Figure 2.6) is a tangible museum guide system that supports families and/or small groups to learn through social interactions (Wakkary et al., 2009). In the game, players repair a time map together by finding historical information in the museum using different handheld tangible devices as well as a PDA and tabletop display. A constructivist learning model with phases of exploration, invention, and discovery was embedded in the game design.

Antle, Wise and Nielsen (2011) designed Towards Utopia (Figure 2.7), a single-player tangible tabletop environment that supported children to learn about key concepts about sustainable development. Children assigned various land uses to different locations by using physical stamps to stamp the land use types on a topographic map displayed on a multi-touch table. The design features of Towards Utopia were grounded in multiple perspectives of cognitive load theory and constructivist learning theories. Building on Towards Utopia and Futura (a multi-touch tabletop system that facilitates collaborative play of a land use planning game (Antle, Bevans, et al., 2011)), Antle, Wise, Hall, et al. (2013) designed Youtopia (Figure 2.8), a hybrid tangible and multi-touch system that supported elementary school aged children to learn about building sustainable community by doing land use planning activities together. In particular, they investigated whether the mechanism of positive co-dependent input from multiple players could promote collaboration and negotiation among children.
2.1.3. **Empirical Studies**

Researchers have conducted empirical studies to test theoretical assumptions about the various learning benefits of TUIs, and to investigate the mechanisms by which tangibles may support learning. I critically review a few representative works here, in which researchers have investigated the learning mechanisms of tangibles from different perspectives with different research paradigms.

Price et al. (2009) designed a tangible tabletop interface that supported children to learn about light behavior. They used it as the research instrument to investigate how the location of the digital representation and the metaphorical mapping between the digital representation and the input object or action affect interaction and learning. This empirical study was drawn upon a design framework by Price et al. (2008) that mapped the key artifact-action-representation relationships of TUIs in the context of learning. Price et al. found that the location of digital representations affected the abstraction level of the concept conveyed. The co-location of digital representations and artifact/action fostered collaborative learning, but may at the cost of reduced reflection opportunities. Their findings equip tangible designers with an empirically validated parameter (i.e., the location of digital representations) to manipulate when they want to show the learning idea at varied levels of abstraction.

To test a popular assumption in the TUI community that direct physical manipulation supports spatial problem solving, Antle, Droumeva and Ha (2009) compared how children solved a jigsaw puzzle using tangible, mouse-based, and traditional physical inputs. They found that more children were able to solve the puzzle and they solved the puzzle faster using the tangible version. Moreover, children exhibited more exploratory actions followed by direct placement later in the tangible approach, which suggested that children gradually developed a mental model of the task. In contrast, children made more indirect actions using the mouse-based approach throughout the session, which suggests that they mostly relied on trial-and-error strategy. Antle, Droumeva and Ha’s work contributes empirical evidence about the benefits of TUIs for spatial tasks, and may inform the design of tangible systems to support learning that involves spatial thinking.
Marshall et al. (2009) observed that in a collaborative design task children resorted to different strategies to prevent others from accessing shared resources when they used cardboard objects versus graphic icons on a multi-touch tabletop. The physical qualities of tangible objects enabled children to use less aggressive strategies to maintain control of their objects. Marshall et al.’s findings provide evidence about the benefits of tangibles in supporting collaborative learning.

Manches, O’Malley and Benford (2010) conducted three comparative studies to explore how the manipulative properties of different representations (physical objects, drawings on paper, graphic representations on a laptop screen) affected the strategies that children used to solve a numerical partitioning task. Their findings suggested that solving numerical tasks with concrete materials may support children to develop symbolic reasoning about the numerical problem. Manches’ work provides tangible designers with some sensitizing concepts to inform their interface choices when they design to support different numerical learning activities.

Horn, Crouser and Bers (2011) compared children’s use of TUIs and GUIs in creating computer programs in a variety of real-life learning environments. Their goal was to gain a comprehensive understanding about the effectiveness of tangibles in support learning, rather than just seek evidence of the “superiority” of TUIs over traditional interfaces. They found that tangibles were better at attracting people to participate and supporting collaborative learning activities. TUIs were also easier to use for children with developing fine motor skills. On the other hand, some children found GUIs easier and quicker to use. These findings inspired them to investigate how children created programs in a hybrid TUI-GUI interface. They found that children used TUIs for early exploration and used GUIs for quick iterative prototyping, and children were able to fluidly transition between the two interaction styles. Horn’s work provides designers with some graspable handles about what features of the learning systems may be worth being implemented tangibly and about how to use a hybrid approach to provide scaffolding for learners. Moreover, Horn’s creation and advocation of hybrid interface inspires the research community to think beyond TUIs as a replacement or “antithesis” of GUIs (Zaman, Vanden Abeele, Markopoulos, & Marshall, 2012), thus providing a new perspective for TUI research.
To summarize, empirical studies about TUIs for learning are fledging. Still, most empirical studies to date focus on how the features of different tangible user interfaces affect learning processes. I still lack empirical evidence on whether tangibles improve the learning outcomes (Zaman et al., 2012). Moreover, many more empirical studies need to be conducted to unveil many unknown specific mechanisms by which tangibles support different learning activities (Antle & Wise, 2013; Zaman et al., 2012).

2.1.4. **Tangible Design Frameworks**

Design knowledge about tangibles for learning has also been accumulating over the years, derived from cognitive and learning theories and also grounded in empirical studies. Design frameworks are a form of design knowledge (Antle & Wise, 2013). They are “overarching conceptual structures” that encompass other forms of design knowledge” (Mazalek & van den Hoven, 2009). According to Antle and Wise (2013), depending on the specificity level, frameworks can take a few forms with varying levels of functionality. In this section, I provide a critical review of the existing tangible design frameworks that focus on or are relevant to learning, categorized by the criteria that Antle and Wise defined. I also justify why I choose the Tangible Learning Design Framework by Antle and Wise (2013) as the literature source for the tangible cards of my Tango Cards.

The first category of design frameworks is taxonomies. They map out the design space by providing categories, dimensions, or elements. For example, Zuckerman et al. (2005) proposed a taxonomy for manipulatives used in education: Froebel-inspired Manipulatives (FiMs) for modeling real-world structures and Montessori-inspired Manipulatives (MiMs) for modeling more abstract structures. Such frameworks provide a classification tool. This category of frameworks provide a useful classification tool, but the level of detail is far too general to serve as actionable guidelines.

The second category is *descriptive* frameworks that are more specific, “providing sensitizing concepts, design considerations, heuristics and the like, but [they do not] provide explanatory accounts of framework relations” (Antle & Wise, 2013). Descriptive design frameworks can be used informatively to help design decision-making as well as
analytically to guide evaluation. Marshall (2007) developed an analytic framework about learning with tangible interfaces that consisted of six perspectives. For each perspective, he reviewed and analyzed prior tangible research, linking to cognition and education theories and raised assumptions to guide future work. Price et al. (2008) developed an analytical framework to inform the design of and structure the analysis of the external representation of TUIs to support learning. Rogers and Muller (2006) conceptualized through a framework how to exploit the lack of control of sensor-based interactions for learning benefits such as promoting exploratory, playful user experience and triggering reflection. Hornecker and Burr (2006) developed a framework for the social experience and collaboration of tangible interactions. Compared with the first category, these frameworks provide more details to inform design. However, they lack explicit, actionable design guidance (e.g. (Marshall, 2007)), and/or they only address one dimension of the TUI learning design (e.g., (Hornecker & Buur, 2006; Price et al., 2008; Rogers & Muller, 2006)).

The third category is explanatory frameworks. As well as the functions that descriptive frameworks provide, explanatory frameworks also explain how and why certain design features can create certain effects, thus providing testable assumptions to direct future research. The Child Tangible Interaction (CTI) Framework (Antle, 2007) is a preliminary explanatory design framework that conceptualized how to design tangible and spatial interactions to support the cognitive development of children.

Tangible Learning Design Framework by Antle and Wise (2013) is the first explanatory framework for tangible learning design, providing specific, testable mechanisms by which different features of TUIs might facilitate learning. In this framework, the authors identified five important elements for TUI learning design (physical objects, digital objects, actions on objects, informational relations, and learning activities). The authors then proposed 13 design guidelines (see Appendix B) that are grounded in cognition and learning theories to inform the design of these elements. Findings from empirical studies were provided to support the guidelines when available. As the authors claimed, this framework could be used as prescriptive design guidelines, evaluation heuristics, and testable hypotheses.
Tangible Learning Design Framework represents the most current efforts of advancing thinking of designing TUI for learning. It is comprehensive in scope. It provides specific guidance on how to manipulate specific TUI feature to achieve a desired learning benefit, which is meaningful and easy to apply to apply design practice. For these reasons, I chose it as the TUI literature source for my Tango Cards.

2.2. Digital Learning Games

Games are “organized play”. According to Prensky (2007), games should have six key structural elements: rules; goals and objectives; outcomes and feedback; conflict/competition/challenge/opposition; interaction; and representation or story. Digital games operate on personal computers, game consoles, or mobile devices. With their embedded computing power, they process players’ input according to game rules and provide multi-media feedback (Prensky, 2007).

Learning games aim to harness the engaging power of games to support learning rather than for pure entertainment. Learning games are also known as educational games (Fisch, 2005; Klopfer & Osterweil, 2013). Other related and overlapping terms include serious games (de Castell & Jenson, 2006; Marsh et al., 2012), game-based learning (Squire, 2003), and edutainment (Kirriemuir & McFarlane, 2004; Klopfer & Osterweil, 2013). The term edutainment is no longer popular due to its negative associations that were caused by some problematic notions and practices that I will describe in 2.2.3 (Klopfer & Osterweil, 2013).

2.2.1. Why Learning Games

"No compulsory learning can remain in the soul... In teaching children, train them by a kind of game, and you will be able to see more clearly the natural bent of each," said Plato in his book The Republic (Prensky, 2007). “Play is our brain’s favourite way of learning,” Diane Ackerman stated in her book Deep Play (Ackerman, 2000). Prensky (2007) claimed that pleasure and fun were two important motivations to create truly learner-centered learning experience for the new generation, who have unprecedented exposure to new technologies and computer games, and have a different thinking and
learning style from preceding generations. Games are also often social by nature, thus supporting collaborative learning (Kirriemuir & McFarlane, 2004).

Despite that mastering a complex video game requires a serious amount of learning effort, gamers would voluntarily and engagingly spend time on it. In fact, the deepest fun comes from this process (Gee, 2007a; Papert, 1988). This suggests that good learning principles are likely employed by good games. According to Gee (2007b), game is the best instantiation of the situated learning theory. Researchers of situated learning theory argued that knowledge was essentially "situated" and thus should not be detached from the context in which it was constructed and actualized. Accordingly, they though studying individuals’ context-dependant developmental paths was more meaningful than studying human beings’ general cognitive development (Ackerman, n.d.). Games support learning through doing and creating, observing consequences, and reflecting on them (Gee, 2007b).

The power of computation in enhancing gaming and learning experience has been widely recognized. Computation can support real-time 3D rendering; multimedia, real-time communication; as well as simulate dynamic processes, to name just a few (Squire, 2008b). Moreover, as postulated by constructionists, computers significantly enhance people's “bricolage” experience, especially in the science and math learning (Papert, 1994). According to Papert (1994), people often practice "bricolage" in their natural learning process. That is, they start with what they have, learn what they need to fix the problems, and arrive at an outcome that they may never plan before. “Bricolage” is a great way to make, fix, and improve mental constructions "in the world". Therefore, video games have an extra edge on supporting learning compared with traditional games.

### 2.2.2. Learning Game Examples

There are some well-designed commercial video games that are not specific learning games per se, but embody good learning principles (Gee, 2007b). SimCity¹ is

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an urban planning simulation game available for the computer and console platforms. It has been applied to classroom settings, and researchers have found that it can support learning skills about mathematics, urban planning, economics, and engineering (Kirriemuir & McFarlane, 2004). As another example, World of Warcraft\(^2\) is a massive multiplayer online role-playing game (MMORG), in which players develop their characters through activities such as hunting, gathering, questing, battling, and crafting in a fantasy world. Research has shown that playing World of Warcraft fosters “scientific habits of mind” (Steinkuehler & Chmiel, 2006).

Research prototypes have also emerged, approaching this goal from different directions and/or focuses: explored the potential of a specific medium in support learning (e.g., (Antle, Wise & Nielsen, 2011; Squire & Jan, 2007)), examined the effectiveness of a specific mechanism (e.g., (Marsh et al., 2012)), and experimented a new paradigm of game-based learning (e.g., (de Castell & Jenson, 2007)).

Squire and Jan (2007) designed Mad City Mystery, a location-based, augmented reality game on PDAs to investigate the potential of this medium to foster scientific inquiry. In the game, players worked in teams to investigate the mysterious death of the game character Ivan by interviewing virtual characters, gathered data samples, and examined government documents, through which players were expected to develop scientific inquiry and argumentation skills.

To explore the learning opportunities embedded in the new design space of multi-touch tabletops, Antle, Bevans, et al. (2011) designed Futura, a collaborative game on a multi-touch tabletop with the learning goal of improving players’ understanding of the complexity of sustainable community development. In the game, players on each side of a table were in charge of one type of resource and they had to work together to win; that is, to meet the needs of both people and environment.

\textit{Waker 2.0}\(^3\) is a flash-based learning game to help high school students understand physics concepts of displacement and velocity (Marsh et al., 2011, 2012). It


was developed to investigate the role of narrative in supporting learning and how to blend games with traditional teaching methods into school teaching. Waker adopted both constructionist and instructionist learning design principles.

In addition, as a design experiment of “content-free” learning games, de Castell and Jenson (2007) built Contagion, a flash-based adventure game that aims to impart health-related knowledge.

2.2.3. Edutainment

Before I dive into “good” learning game design theories, I take a quick look here at some earlier “bad” practices of learning games—edutainment. The edutainment of the 1990s had problematic assumptions about and approaches to game-based learning (Klopfer & Osterweil, 2013). It assumed that children did not like learning and thus games were provided along to motivate them and to disguise learning (“the spoonful of sugar that helps the educational medicine go down” (Jenson et al., 2011)). The resulting edutainment design was often drill and practice followed by some reward such as animation and sound effects (Kirriemuir & McFarlane, 2004; Resnick, 1998). Such payoff provided some motivation for learning. However, such an approach treated gameplay as an enticement for learning, rather than part of learning. Research has found that such “enticement details” did not work as children tended to remember the enticement rather than the educational content (Fisch, 2005).

2.2.4. Important Notions

Before I review the design theories that are directly related to game-based learning, I spend some time here and look at a couple of general concepts. Although they do not directly address the domain of game-based learning, they have inspired and guided a few prominent researchers in this domain, including those discussed in this thesis.
The Flow State

“Flow state” was coined by Csikszentmihalyi (2008) to describe a state that people are in when they are engaged in *intrinsically motivating* activities. “Flow state” is an important concept and study subject in the learning and game design research, because it identifies one of the ultimate goals of learning game design. As Presnky (2007) claimed, one of the biggest challenges for designing digital learning game was to keep players in the flow state for both game play and learning. Prensky (2007, p. 124) provided a description of the flow state:

“In the flow state, the challenges presented and your ability to solve them are almost perfectly matched, and you often accomplish things that you didn’t think you could, along with a great deal of pleasure. There can be flow in work, sports, and even learning, such as when concepts become clear and how to solve problems obvious.”

Hard Fun

An idea closely related to “flow state” is “hard fun”. Papert (1988) argued that learning should be “hard fun”. In contrast to the edutainment notion of “making it easy” and using games to hide learning, Papert claimed that the best learning happens when one was deeply engaged in hard and challenging activities. He thought that making the learning activities easy and light actually deprived children from having fun.

2.2.5. Theory Development of Learning Games

Compared to the design theories on tangibles for learning, the domain of designing learning games is less developed. Here I review a few research works that have contributed knowledge in a variety of forms to this field. I also explain why I chose Gee’s design principles (Gee, 2007a) as the major literature source for the game cards of Tango Cards.

When I review these different forms of design knowledge accumulated in this area, I follow these criteria:

- How was the design knowledge generated? How much can I trust it? Has it been empirically validated?
• How actionable is the design knowledge? Is it at a level of detail sufficient to inform specific design decisions?

Malone (1981) made one of earliest inquiries into what made computer games so intrinsically motivating, and how could such features be applied to computer-based learning activities. In his influential paper based on his PhD dissertation, Malone laid out a rudimentary framework about intrinsically motivating learning, as the preliminary result of his inquiry. This framework was based on a review of previous theories on intrinsic motivating and his own empirical studies. The frameworks consisted of three elements:

• Challenge: The learning activity must have a personally meaningful goal.
• Fantasy: The activity should apply fantasy that is intrinsically related to the skills taught.
• Curiosity: Optimal curiosity can be evoked when "the learner knows enough to have expectations about what will happen, but where these expectations are sometimes unmet."

One important concept coined by Malone (1981) is intrinsic versus extrinsic fantasies. In games adopting intrinsic fantasies, the games and the skills being learned are interdependent, and the learning content is an indispensable part of the game structure. On the other hand, in games using extrinsic fantasies, the games depend on the skill being learned, but not vice versa. The same fantasy can be applied to other learning contents. Malone advocated for intrinsic games because they have more learning power and are more engaging.

As Malone (1981) suggested, his framework can be used as a checklist of heuristics; for example, to evaluate and improve an existing learning design by adding intrinsic motivating factors. On the other hand, as Malone acknowledged, this initial step of investigating "what makes things fun to learn" focused more on the fun part rather than on the learning effectiveness part. The principles outlined were only partially validated by the author's own empirical studies. Moreover, these principles stayed at a broad level without specific design guidelines to make them more actionable.

In his book Digital Game-Based Learning (Prensky, 2007), Prensky (2007, p. 156) set out a taxonomy that matches learning content, learning activities, to different types of games. For example, Prensky considered role-playing games were suitable for teaching
content such as behaviours and judgements, while simulation games were good at educating procedures and systems. However, as Jenson, Taylor and de Castell (2011) criticized, such approaches separated learning content from game play. The resulting games rarely had engaging power that can make children play voluntarily. Prensky also provided his preliminary list of design principles for digital game-based learning. The principles included: the game should be fun; users should feel they are playing rather than learning; the game should be addictive; users should learn effectively from playing the game; and the game should encourage reflection. I consider these superficial criteria for good learning games rather than real “principles” about how to design good learning games. Prensky’s book does a good job at promoting the value of digital games for supporting learning and provides a comprehensive review of previous works. However, his “design principles” were too vague and were derived without methodological rigour.

Gee (2007a, 2007b), a renowned learning science and literacy researcher, as well as an avid video gamer, inquired into what made games so intrinsically motivating and how to incorporate these elements of games into learning design. Gee approached his investigation by analyzing well-designed video games and reviewing learning science research. He distilled his findings from his analysis into 13 learning principles that he believed should be applied to school learning (Gee, 2007a) (see Appendix C).

For each principle, Gee (2007a) first described how it was used in video games, followed by a concrete game example, and then he discussed how this principle could be applied to school education. A core idea was "learning to be". Gee called for deep learning; that is, learning beyond the facts and learning to apply and transfer the knowledge for innovation. Gee argued that for deep learning to happen, learners should be able to experience the feel of an "authentic professional" during the learning, before they really (ever) reach the level of expertise of professionals (he calls this "performance before competence"). By authentic professionals, Gee referred to veterans in a field who were very good at their jobs and whose ways of thinking and behaving and values had been strongly influenced by what they do. Gee also suggested providing "smart tools"—tools and technologies that had build-in knowledge and skills and could be integrated with learners’ own knowledge to empower users to think and act like "authentic professionals."
Gee’s learning design principles cover many dimensions of learning game design. His work has been widely cited and strongly influenced game and learning researchers that followed him (e.g., Kurt Squire and Eric Klopfer, whose work I will discuss in section 2.2.6 and 2.2.7). The limitation of Gee’s work is that he did not empirically validate his principles. On the bright side, following researchers (e.g., Squire and Klopfer) have started to provide some empirical evidence for Gee’s claims (see 2.2.7). I consider Gee’s theory the best among all the available literature considering its comprehensiveness, level of details, and actionability. Therefore, I chose it as a major knowledge source for the game cards of Tango Cards.

Drawing upon his rich experience in designing educational games for children, Fisch (2005) elucidated three design considerations on how to integrate educational content effectively into game play, supported by real-life examples from the his design practice of children learning games. The considerations included: select a medium that best matches the educational topic or concepts; make the educational content intrinsic to gameplay; and provide feedback and hints that support and scaffold learners in finding the solutions. With a satisfactory level of concreteness and specificness to inform design, Fisch’s considerations serve as another knowledge source for the game cards of Tango Cards (see Appendix C).

2.2.6. Theory Advancement Driven by Empirical Research

A new wave of game-based learning research has taken a more empirical approach. Researchers have provided empirical evidence for some existing theories, and/or generated preliminary theories in some new directions.

Through a critical review of emerging game-based learning literature, a content analysis of the game-based learning products made by several successful programs and/or companies, and interviews with designers of these game-based learning companies, Squire (2008a) put forward a framework to understand game-based learning. His new learning model emphasises on providing players with compelling experiences, both emotionally and intelligently. He claimed that the context in which learners develop knowledge, rather than the content alone, is the “king”. Besides the
ideas mentioned above, this “emerging paradigm” of game-based learning also includes the following core principles. For each principle, Squire provided game examples and designers’ quotations for explanation and support.

- Situate learners in complex information management and decision-making situations where facts and knowledge are drawn on for the purpose of doing;
- Provide challenges that confront and build on users’ pre-existing beliefs, thus leading to productive future understandings;
- Anticipate the users’ experiences from moment to moment, providing a range of activities to address learners’ needs;
- Invite the learner to participate in constructing the solutions and interpretations;
- Embrace the ideologically driven nature of education and training.

The strong influence of Gee’s (2007a, 2007b) thoughts on learning design is clear in Squire’s framework. Unlike Gee’s learning principles, which were based solely on content analysis of well-designed video games, Squire’s framework (2008a) was largely derived from his three case studies with leading game-based learning companies (in addition to game analysis and literature review). This made Squire’s work better empirically grounded. Squire also advanced thinking in how to apply good learning principles in video games to the design of game-based situated learning. On the other hand, Squire’s framework is still at a rudimentary stage. Further user studies are needed to flesh out the framework and make it more usable, as well as to provide more definite evidence.

Through a design-oriented research (Fallman, 2003) about a web-based learning game Contagion (which aims to educate teenagers about the knowledge and behaviours for preventing and combating four virulent deceases that threaten public safety), de Castell and Jenson (2007) explored what “educational” and “content” meant. They realized from their design research practice that the popular notion of “embedding content integrally into game play” (e.g., as claimed by (Fisch, 2005)) was shallow and unproductive. They argued that actually content was ubiquitous in the game and could be enacted through all aspects of the game, such as character selection, art, narrative, programming, and goals. Therefore, they believed what game designers should achieve
was to design a holistic, rich, complex learning/game environment that could engage players “willingly and wittingly”. Learning would come naturally in such environments.

de Castell and Jenson’s (2007) idea of building an attentionally engaging environment is consistent with Squire’s principle of creating compelling experience (Squire, 2008a). The theories that Squire as well as de Castell and Jenson developed through first-person investigation have enriched Gee’s deep learning and identity principles and extend it to the practice of game-based learning design. That the two groups of researchers arrived at similar ideas using different methodologies without influence from one another (they didn’t cite each other’s work) gives more weight to this new way of thinking of and approaching game-based learning design. That being said, de Castell and Jenson’s research was at a preliminary stage too. The ideas are still vague. Further development and validation are required.

Regarding research methodology, Gee (2007a, 2007b) generated his learning design principles through game analysis and literature review. His study was based on others’ work, which is an indirect (“third person”) approach of investigation. On the other hand, Squire (2008a) as well as de Castell and Jenson (2007) used more empirical approaches; that is, their studies were mostly based on their direct (“first person”) investigation. Squire conducted interviews with game companies. de Castell and Jenson gained their insights through designing a web-based learning game (conducted a design-oriented research).

Unlike Squire as well as de Castell and Jenson, whose research contributed new understanding about how to design game-based gaming, Shaffer (2006) contributed new understanding about how and why video games support learning. Shaffer proposed a mechanism that he called “epistemic frames” to explain how students transfer their experience with video games and interactive learning environments to situations in the real world, both in and outside school. He defined epistemic frames as “the ways of knowing, of deciding what is worth knowing, and of adding to the collective body of knowledge and understanding of a community of practice.” Shaffer developed the concept of epistemic frames from the concept of islands of expertise—“any topic in which children happen to become interested and in which they develop relatively deep
and rich knowledge” (Crowley & Jacobs, 2002). He also added that the development of identity was an important part of the development of islands of expertise. Shaffer claimed that the development of islands of expertise led to the development of epistemic frames.

Shaffer (2006) also provided evidence about epistemic frames from two empirical studies he conducted involving role-playing games. He acknowledged that the evidence was illustrative, preliminary rather than conclusive. Shaffer’s work is very valuable in its new understanding and further support about the value of video games to support learning. However, from a practical perspective, his work does not lend itself to actionable design knowledge to guide the design of learning games.

2.2.7. Empirical Studies

As the last part of my literature review of learning games, I describe several empirical studies. Unlike the empirical research works mentioned in the sections previously, these works did not aim to contribute general guidelines about how to design learning games. Instead, their work contributed empirical evidence about the effectiveness of some specific mechanics of digital learning games.

Through a design-based research approach, Squire and Jan (2007) investigated whether location-based augmented reality games on handhelds can help students develop scientific argumentation skills. Augmented reality games are “games played in the real world with the support of digital devices (PDAs, cellphones) that create a fictional layer on top of the real world context”. They designed Mad City Mystery, an augmented mystery game as the research vehicle, and conducted three case studies with three groups of participants of different age ranges on the University of Wisconsin-Madison campus. They found evidence that students developed scientific argumentation skills in this augmented simulation gaming environment. In particular, role-playing and place-based design features helped scaffold students’ thinking. Their findings provide empirical support for Gee’s concept of “projective identities”—identities that “are a melding between the game player and the role (or scientific profession)” (Gee, 2007b).

Marsh et al. (2012) conducted a study to compare the efficacy of three learning approaches: “on-game” (using Waker, an interactive puzzle game they developed;
versions \textit{with} and \textit{without} narrative and character, see 2.2.2 for details), “off-game” (using animation and teacher instead of the learning game), as well as “blended” (a combination of the first two approaches) learning approaches in teaching high school students physics concepts and motion graphs. They found that students had more fun and learned better using games with narrative and characters than using puzzle games without narrative and characters. Their findings provide empirical support for the effectiveness of narrative in support learning.

As an “educational game design experiment”, Jenson et al. (2011) designed and evaluated \textit{Epidemic}, a game to impart knowledge about preventing and treating contagious diseases. They continued their exploration of building “content-free” games that they started with game \textit{Contagion} (de Castell & Jenson, 2007). By “content-free”, they meant that knowledge and content should not be limited to a “textual and propositionally-organized form”. Rather, content can be enacted through multiple modalities and aspects of a game environment, such as narrative, character, and game mechanics. This time the authors utilized social networking tools, such as social networking site, poster-creation game, and fictions disease creation tool, to encourage collaborative learning. Then they did a qualitative evaluation of whether the game supported “sustained and voluntary attention-giving” and improved students’ understanding of the involved health concepts. The result was positive. They also found evidence that such a design supported collaborative learning. Jenson’s study provided preliminary support for the effectiveness of a “content-free” collaborative environment in supporting learning.

As shown in the review above, a solid body of design theories and knowledge has been developed about digital learning games. Although a comprehensive and actionable framework is still lacking and many theories still call for further empirical studies, it is time to start bringing this body of knowledge to design practice.

\section*{2.3. Tangible Learning Games}

\textit{Tangible Learning Games}, the subject of this thesis, are learning games that involve tangible interactions. Actually most of the example tangible learning systems that
I introduced in section 2.1.2 have some game elements. Many support open-ended learning activities and are playful by nature. Some even look like toys; for example, Digital Manipulatives of *Programmable Bricks, BitBalls, and Digital Beads* (Resnick, 1998); *Backpacks and Topobo* (Raffle et al., 2006). *Kurio* (Wakkary et al., 2009) and *Youtopia* (Antle, Wise, Hall, et al., 2013) explicitly employ game mechanics, though the game mechanics in these games are usually much simpler compared with their video games counterparts.

### 2.4. Design Knowledge, Design Methods and Tools

The goal of interaction-design research, like academic research in general, is to produce and communicate knowledge. According to Höök & Löwgren (2012), the knowledge space created by HCI research can be categorized using a dimension related to *level of abstraction*, with at one end particular artefacts that are not abstracted at all; and at the other end general theories that hold across all situations. Design guidelines and frameworks are two forms of closely related design knowledge of intermediate-high level of abstraction. They have been widely used by researchers in the human-computer interaction field to construct and communicate knowledge. Design guidelines make general theories more operational and useful (Löwgren, 2013). Design frameworks help structure the understanding of the design space and highlight its key characteristics.

As an accurate and detailed form of the design knowledge, design guidelines and frameworks are an effective form in supporting communication in academia. On the downside, they are still abstract and may be dense, which makes them hard to use in design practice (Hornecker, 2010). Rogers (2004) calls for new mechanisms of *knowledge transfer between design theory and practice* that go beyond design guidelines and frameworks, which are “more lightweight and accessible”.

There exist a variety of forms of *intermediate-level knowledge* that resides in the territory between the two end points in Höök and Löwgren’s design knowledge diagram (2012), such as design patterns, strong concepts, design tools and methods, and heuristics. Design researchers have investigated the utility of these knowledge forms in
constructing knowledge and bringing theory to practice, as exemplified by (Höök & Löwgren, 2012; Löwgren, 2013; Stolterman & Wiberg, 2010).

In particular, design tools and methods are a well-established form to carry intermediate-high abstraction level of knowledge, with their abstraction level spanning a broad range (Höök & Löwgren, 2012; Löwgren, 2013). For example, a Cognitive Walk-through is a usability inspection method that used by usability experts to understand what problems users would have when they learn to use the interface (Dix et al., 2003). Design tools can take many forms, from a software application (such as ECLIPSE direct manipulation tool) to physical forms such as design cards (Bekker & Antle, 2011), as I will discuss in the next section.

2.5. Cards as a Design Tool

In particular, card-based design tools have been used by a number of researchers to make knowledge produced by design-based research as well as other domain knowledge accessible to designers (Bekker & Antle, 2011; Halskov & Dalsgård, 2006; Hornecker, 2010; Lucero & Arrasvuori, 2010). They are hand-sized and typically contain both text and pictures. Researchers have found design cards to be effective as knowledge “transfer vehicles” between theory and practice (Rogers, 2004). Hornecker (2010) transformed her Tangible Interaction Framework (Hornecker & Buur, 2006) into Tangible Interaction Cards (Figure 2.11) to make the concepts better fit into the ideation flow. PLEX Cards (Lucero & Arrasvuori, 2010) (Figure 2.9) were created by Nokia researchers to communicate the Playful Experiences (PLEX) framework to designers in a form that was more accessible in design discussions. Bekker and Antle (2011) created DSD Cards (Figure 2.10) to make information about children’s cognitive, physical, social, and emotional abilities at different ages accessible to designers of children’s products. Halskov and Dalsgård (2006) created Inspiration Cards (Figure 2.12) to bring existing technology and applications (communicated by the Technology Cards) as well as knowledge about the specific project under design (communicated by the Domain Cards) closer to designers as sources of inspiration. They aimed to facilitate designers’ “reflective conversation” between the repertoire and the situation (Schön, 1987). IDEO
LOCOMOTION

Does the design encourage maintaining balance during simple movements?
Can the design evaluate the quality of movements such as running in place or jumping?
Can the design help children practise balance and agility through simple activities?

Designer Tips:

Can users grab, feel and move “the important stuff”?

Tangible Manipulation > Haptic Direct Manipulation

Can users grab, feel and move “the important stuff”?

The All-Seeing Eye

A camera tracks the movements of an object. A video-stream showing a close-up of an eye is adjusted to make it seem that the eye focuses on the object and follows it around.

Figure 2.9. A PLEX Card

Figure 2.10. A DSD II Card

Figure 2.11. A Tangible Interaction Card

Figure 2.12. An Inspiration Technology Card
From “Inspiration Cards,” by P. Dalsgård, 2006, Copyright 2006 by Peter Dalsgård. Used with permission.
created Methods Cards\textsuperscript{4} to expose designers to a variety of methods that they can use to understand the people they are designing for.

In studies of design cards, researchers have found that cards can help structure design discussions, ensuring a design space is viewed from different perspectives. Cards can help speed up the refinement and iteration of ideas (Bekker & Antle, 2011; Lucero & Arrasvuori, 2010). Cards can also help kick off design discussion and foster a focus shift when the discussion becomes unproductive (Halskov & Dalsgård, 2006; Hornecker, 2010). The information on the cards provides designers with a common vocabulary to use in design discussion (Halskov & Dalsgård, 2006; Lucero & Arrasvuori, 2010). Cards can also be used to plan and guide evaluation (Hornecker, 2010; Lucero & Arrasvuori, 2010; Lucero et al., 2013).

In particular, the form of cards is important in terms of how the cards support designers. The small physical form of cards affords physical manipulation (Hornecker, 2010). Cards can serve as a physical reference during design discussion, facilitating communication and shared understanding (Bekker & Antle, 2011; Hornecker, 2010). Cards can be used to bookmark discussion ideas (Hornecker, 2010; Lucero & Arrasvuori, 2010). Indeed, as Hornecker claims, using cards is tangible interaction (Hornecker, 2010).

All these cards mentioned above except the DSD Cards focus on \textit{inspiring} designers. They are targeted primarily at the \textit{early stage} of the design process. In particular, Tangible Interaction Cards and PLEX Cards explicitly mentioned their goal of “[supporting] the free flow of ideas” and “better [fitting] in the dynamics of a design discussion”. On the other hand, DSD Cards aimed to \textit{inform} and \textit{inspire} designers in different design activities throughout the design process.

All these cards except the DSD Cards have \textit{methods} associated with them. Tangible Interaction Cards are supposed to be used in a game format. PLEX Cards can be used with the PLEX Brainstorming and PLEX Scenario techniques. Inspiration Cards

are expanded by a loosely structured workshop with supplementary materials such as images, video clips, and posters.

Each set of cards serves as a useful design tool for its specific design space, often enabling the transfer of knowledge from academe to design practice. The findings of these studies also provide empirical support for the effectiveness of cards in bringing design knowledge to the design practice. However, card research to date deals with specific design spaces. It has not been abstracted to design spaces in general. Nor have researchers always articulated what design knowledge was embedded in their card artefacts. Another limitation of previous work is that most card sets were designed to provide inspiration in the early stage of a design process (e.g. (Halskov & Dalsgård, 2006; Hornecker, 2010; Lucero & Arrasvuori, 2010)). Less is known about how to design cards that can inform designers and can be used at various stages of design.

As demonstrated in the literature reviews of this chapter, the research of both TUIs for learning and digital learning games has generated a solid body of design knowledge. It is time to bring this knowledge to design practice. Design Cards might be suitable as a knowledge transfer vehicle that bridges the gap between scholar design research about tangible learning games and the design practice of such games. Meanwhile, regarding the research of design cards as a knowledge transfer tool, it is also time to start synthesizing and abstracting existing knowledge about how to design cards to make it more generalizable. My research of Tango Cards was driven by both needs.
3. Designing the Tango Cards

In this chapter I discuss the design of Tango Cards. I also describe the design goals, design process, major design challenges, and the rationale for my key design decisions. I close this chapter with a report on the findings of the expert reviews of the cards and a list of revisions.

3.1. Design Goals and Requirements

The primary design goal of Tango Cards is to make academic knowledge about designing tangible learning games accessible to designers in different activities throughout the design process. Priority is given to communicate the source knowledge accurately as well as make the knowledge easy to understand and apply. The inspirational power is of second priority.

3.2. Target Audience

Considering that tangible learning games are still in their infancy and mostly exist in laboratories as research prototypes, the target audience of Tango Cards for now and the immediate future is design researchers and students. However, in the long term (hopefully in the near future) design practitioners in industry will also get involved in designing tangible learning games. I designed Tango Cards with both the current and future target users in mind.

3.3. Design Process

My card design was informed by previous card works (Bekker & Antle, 2011; Halskov & Dalsgård, 2006; Hornecker, 2010; Lucero & Arrasvuori, 2010) and guided by
the design goal of Tango Cards; that is, to make academic design knowledge about tangible learning games accessible to designers in their design process, with a focusing on informing. I first decided the card structure; that is, the sections a card includes and their special layout (as described in details in section 3.4). I used this as a template to guide me in transforming source design literature to information for different sections on the cards. I also selected image examples for each card. I went through several internal iterations. For each pass, I asked my supervisor Dr. Antle and Dr. Neustaedter to review the cards. I developed another iteration of the cards by incorporating their feedback. After that, I invited four researchers with expertise in TUIs, game design, or learning science to do an expert review. I revised the cards based on their feedback. The final design is a set of 25 cards, approximately 3.8” by 4.4” in size. A PDF copy of the cards can be downloaded from 

http://antle.iat.sfu.ca/tangocards

3.4. Tango Cards Design

Tango Cards consist of two categories: cards about tangibles and cards about games. The learning aspect is embedded in all cards. The cards are colour-coded by category: blue colour for the 11 tangible learning cards (Figure 3.1 and 3.3), and orange colour for the 14 game cards (Figure 3.2 and 3.4). These colours are very distinct, which enables designers to sort the cards by category when needed. For example, when they are unfamiliar with only one category of knowledge.

My review revealed that cards intended for inspirational use (e.g., (Hornecker, 2010; Lucero & Arrasvuori, 2010)), tend to include only a few words related to a concept on each card. My priority for Tango Cards was to inform designers. Therefore I needed to include more information about each concept on my cards to avoid vagueness. Based
Linking through Metaphors

**Consider:** Does the TUI use simple metaphors, like “up is more” and “big is important,” to link properties of (or actions on) physical objects and the digital representations of concepts?

**Why:** This can improve users' understanding of abstract concepts.

**Example:** By linking the size of TUI objects to the level of importance of related digital representations using the "small-big" metaphor, you can help users understand the concept of “importance.”

Figure 3.1. A Tangible Card—Text Side

Figure 3.2. A Game Card—Picture Side

Note: The pictures are about *Kurio* (Wakkary et al., 2009). Copyright 2009 by Ron Wakkary. Used with permission.
on the design of IDEO Cards and DSD Cards (Bekker & Antle, 2011) (which cover more information), I decided to include five types of information in the cards. The front side (Figure 3.1 and 3.4) has five elements: title, design consideration (“Consider”), rationale (“Why”), textual example (“Example”), and a label “Tango Cards – Tangible, Learning, Games” in the order from top to bottom. Titles are short, punchy phrases capturing the gist of each concept. The design consideration is framed as a question as inspired by (Hornecker, 2010). The rationale part explains what learning benefits such a design principle can bring. The text example briefly describes one or a couple of general ways to apply the design consideration.

The back of a card (Figure 3.2 and 3.3) contains the card title, a picture example (with a short description), and a QR code (unimplemented). Most pictures are photos of tangible learning systems (games) that demonstrate the design consideration. The picture examples serve as specific, concrete examples of applying the concept.
The information architecture of the cards; that is, the spatial arrangement of different elements as well as the font hierarchy of the elements on the front side aligns with the order of importance of different elements to card use. For example, in order to present the title and design considerations that communicate the core idea of the concept at a glance, I put them at the top of the front side and used large, color font for the title. Designers can choose to continue reading the other elements if they need to.

3.5. Knowledge about Tangible Learning Games

The design space that Tango Cards were designed to support—tangible learning games, actually consists of three dimensions: tangibles, games, and learning, with the learning dimension embedded in the first two; that is, the tangible and game dimensions are learning-focused. It is a complex design space in terms of its multiple dimensions, and the complex design knowledge involved with each dimension.

I translated the knowledge about designing tangibles for learning from the Tangible Learning Design Framework by Antle and Wise (2013). I extracted learning game design principles mainly from the learning principles that Gee (2007a) derived by analyzing examples of good video games through cognitive science lenses, and design considerations that Fisch (2005) summarized by drawing upon his experience designing educational games. As I explained in 2.1.4 and 2.2.5, I chose these literatures as knowledge sources for Tango Cards because they represented the most current and best quality knowledge that were available when I developed the cards (and probably now) in terms of comprehensiveness, actionability, and methodological rigour (i.e., how much I can trust it).

3.6. Developing Card Content

When I developed the content, I used the card structure (i.e., the different card elements as described above) as the “template” to guide us in extracting information from the source literature. I aimed to make the title tantalizing and memorable as well as descriptive. I focused on replacing academic jargon with simpler words to make the
information easier to understand and apply. I thought that this rewriting would be important to both design practitioners and design researchers and students. For example, for tangible card of *Multiple Modalities*, my first version of rationale was worded like this: “This can improve learners’ effective working memory capacity (especially for the visual channel), as the capacity of each individual perception channels is limited.” I later revised it to “This can help users more efficiently take in and use information.” As another example, I didn’t use the term *image schema* used in the source (Antle & Wise, 2013). Instead, I adapted it to *Simple Input Actions* (as the card title). I phrased the corresponding guideline as “Does the TUI use simple, common movement patterns, like in-out, up-down, and fast-slow, for input actions?”

I also replaced some metaphors that may lack universal meanings used in the source with more straightforward descriptions. For example, for the learning game cards, I have two design principles that Gee (2007a) coined as “Fish Tanks” and “Sandboxes”. I replaced Fish Tanks with “Simplified Systems”, and Sandbox with “Low-Risk Exploration” correspondingly.

I also paid attention to provide definitions for terms that I thought might not be commonly known. For example, for card *Intrinsic Rewards*, I embedded explanation in the design consideration: “Are rewards intrinsic to game play? Can rewards enhance user’s game play experience?”

### 3.7. Choosing Image Examples

I chose to use pictures of tangible learning systems (games) for most cards (e.g., *FlowBlocks* (Zuckerman et al., 2005), *Kurio* (Wakkary et al., 2009), *Tern* (Horn et al., 2012), *Bifocal Models* (Blikstein et al., 2012)). For previous cards that focus on inspiring, their picture choice concentrated on inspiration and innovation. Researchers of these cards suggested that picture examples should be familiar to end users and easy to relate to (Hornecker, 2010; Lucero & Arrasvuori, 2010). They argued that the examples should

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5 Tango Card names are capitalized and italicized throughout the thesis. For a complex listing of card names see Appendix A.
not be too specific to constrain the ideation space; nor should they be too general so that designers find it difficult to relate to the examples and apply them to their projects (Halskov & Dalsgård, 2006; Hornecker, 2010; Lucero & Arrasvuori, 2010). Because my focus was informing rather than inspiring, I chose prototypical examples rather than generic examples (Deng, Antle & Neustaedter, 2014). I thought that the former would better serve as sources of information because they would provide more specific, concrete guidance on how the concept could be applied. I considered this to be especially helpful for the domain of tangible learning games, which is still new to many designers. I put the picture example on the back side because of 1) the space constraint of the front side of the cards and 2) their main anticipated use as further reference.

One major challenge that I faced when looking for picture examples was that there are not many tangible learning games. For some concepts, I could not find a suitable prototype example. This was especially the case for some game cards. Many picture examples of tangible cards were from the prototypes mentioned in the source Tangible Learning Design Framework (Antle & Wise, 2013). On the other hand, as the main literature source of game cards, Gee (2007a) used video games as examples. I found it difficult to find suitable counterparts of tangible learning systems/games for some of these game concepts. Those existing ones may incorporate some gaming elements (e.g., Utopia (Antle, Wise & Nielsen, 2011)), but are not strict games. Moreover, I found that a few game design principles did not deal with specific game mechanics, but were at higher level and deal with the structure of the game; for example, The Cycles of Practice and Challenges principle suggests that a learning game should alternate practicing skills and bigger challenges. This deals with the structure of the game rather than a specific feature. I had considered the following options. I was also aware of the drawbacks of each option, especially after hearing feedback from my supervisors.

The first option was screen captures of video game examples that Gee (2007a) provided when explaining his learning principles. For example, a screen capture from the game Full Spectrum Warrior for the Smart Tools concept, which is about embedding in game avatars skills and knowledge that players do not have to make players more powerful in the game world. The problem with this option is that they do not provide
direct, concrete examples as tangible learning games. Moreover, they do not mean much for those who do not know the game.

The second option is metaphorical pictures. For example, a picture of a fish tank to illustrate the game concept of *Simplified Systems*; that is, providing players with a simplified version of the game that highlights its key elements to ease their learning curve. As another example, a picture of road signs (Figure 3.5) for the game concept of *Multiple Pathways*, which claims that games should be customizable to support players of different styles of learning. This choice has universal meanings, but the picture may just repeat in visual form exactly what is already described in text and do not add much.

The third option is pictures of everyday human activity and objects. For example, for the game principle of *Relating Skills to Goals* (which means the game should show players how the skills they practice can help them achieve a meaningful goal so as to motivate the players), I used two pictures to illustrate the concept. That is, practicing hammering a nail (as shown in the left picture of Figure 3.6) is important for achieving the goal of building a tree house (as shown in the right picture of Figure 3.6). Everyday pictures are easy to understand and can communicate the concept very effectively if well
chosen. However, they do not provide directly applicable examples like tangible learning game examples do.

Figure 3.7. ‘Tern’ for the ‘Multiple Pathways’ Card
From Figure 2 and Figure 4 in (Horn, 2012).

Figure 3.8. ‘Bifocal Model’ for the ‘Simplified System’ Card
From “Figure 3” in (Blikstein, 2012).

Figure 3.9. ‘Super Mario’ for the ‘Intrinsic Rewards’ Card
From Super Mario Bros. Copyright by Nintendo. Fair use.

Figure 3.10. Diagram for the ‘Feedback as Scaffold’ Card

My final decision was to use pictures of tangible learning systems if available. For example, for the concept of Multiple Pathways, I replaced the road sign picture with pictures of Tern (Horn, 2012), a programming language that provides both TUI and GUI versions (see Figure 3.7). I used Bifocal models (Blikstein, 2012) for a few game concepts, such as Simplified Systems (see Figure 3.8). As mentioned earlier, one concern with these tangible learning systems is that they are not strictly games. Moreover, pictures of prototypical examples are complex and may be unfamiliar to
designers. They provide more information but also require context to make sense. However, I did not think that providing generic examples from everyday life would be an effective way to communicate the dense concepts in this domain without additional explanation either. That was why I intended to include a QR code to point users to further explanation on the prototype example and other relevant information. The QR code was not implemented due to the time and scope constraints of this thesis. After all, I did not expect participants to use the QR code much in the two design cases of concept development of my user study.

I used pictures of general human activity, commercial video games, and diagrams for a few concepts for which there were no suitable prototype examples to convey the concept (e.g. Super Mario for the Intrinsic Rewards card (Figure 3.9) and a diagram (Figure 3.10) for Feedback as Scaffold).

3.8. Expert Review

3.8.1. Goals and Procedure

After my initial design of the cards, I conducted expert reviews with four researchers. The researchers were three PhD students and one senior researcher with expertise in TUI design, game design, or learning science. They studied or worked in Canada, United States, and Australia. The goal of expert reviews is twofold. First, by identifying quality issues with the cards (e.g., card content, visual design) through expert reviews and fixing these issues, I could better focus on investigating my research questions in the user study. Second, some questions that I asked expert reviewers also probed into research questions. Expert reviewers’ response to these questions served as a pointer to what to pay attention to during the user study.

The expert review is different from inspection techniques such as heuristic evaluation. Although the interview protocol served as a high-level framework, expert reviewers were welcome to bring their unique insights and perspectives into the reviews. Moreover, the opinions of the four expert reviewers provided useful feedback to revise
the cards, but it was my call to accept or reject their ideas based on the design goal of
the cards.

The expert reviewers were provided with an electronic copy of the card set and
my interview questions about a week before the interview on Skype or in person. They
were asked to read the protocol, check the cards, and think of their answers to the
questions before the interview. The interview consisted of 12 open-ended questions,
soliciting feedback on card content (e.g., whether they were easy to understand, whether
they were at the right level of detail, any inaccuracies); image examples (whether they
were helpful in illustrating the guidelines); visual design; their anticipated card uses; and
overall impression about the cards. The interviews took about 1.5 hours and were audio
recorded. See Appendix D for the complete expert review questions.

3.8.2. Results of Expert Review

Expert reviewers generally recognized the cards' value in bringing design
knowledge accessible to designers. E2 and E3 commented that they liked the idea of
bringing design knowledge to designers. E3 also said he liked the “scope and depth of
the information”. E1 stated: "I think these cards are an excellent summation of the core
principles for tangibles and learning design that have emerged in Alissa's (Dr. Antle)
work and in the field in recent years. It's great to see all these design recommendations
clearly spelled out in one place."

Content

Expert reviewers pointed out a few quality issues of the card content, including
instances where they found the wording confusing, inaccurate, or had negative
connotations. For example, E1 expressed that the title “Content on the Plotline” was
confusing. Per his suggestion, I revised it to “Integrating Content and Play”. As another
example, E1 commented that the example of Coherent Mapping was over claimed,
which stated “Pressing the thumbstick of a game controller forward to move an avatar
forward is so intuitive to users that they do not really need to learn about it.” He
suggested instead of asserting such coherent mapping makes learning to use the
interface unnecessary, stating that it eased the learning curve. E2 said that he felt the
title “Codependency” had negative connotation. I changed it to “Codependent Access Point”. In addition, reviewers also gave suggestions on some minor issues, such as use Italics to distinguish the model names and also as a way to credit the authors.

E3 also remarked that the cards contain too much text to be useful for brainstorming. He suggested cutting 75% of the text and using bullet list to better serve quick brainstorming use. I did not take his suggestion because the primary goal of Tango Cards is to inform, not to inspire in brainstorming.

**Picture Examples**

Two reviewers explicitly stated that they found some picture examples difficult to understand. E1 said that those using “scientific learning systems”, such as *Bifocal Model* (Blikstein et al., 2012) were too complex and required much context to make sense. Moreover, he thought such systems did not have game elements in them and were disconnected from the game concept. He suggested using general computer/video game examples. E4 preferred everyday life examples, speaking from his experience designing cards for exertion games. He said that he first used pictures of exertion games, but people did not understand. Then he used pictures Nadal playing tennis and people liked it. He said designers preferred “quick clues”. E2, although shared similar concerns, stated that whether this was going to be a problem depended on the design goal and target user groups. He felt that people in academia were more interested in reading the additional information via QR code to help understanding, while designers may not.

I changed several of these examples accordingly. For example, for the Intrinsic Rewards card, I replaced the Bifocal Model picture with a picture of Mario turning into Super Mario after eating a mushroom as a reward. However, I continued to use tangible learning game pictures for most cards because my priority was informing and I wanted to explore the effectiveness of prototypical examples for informing design.

**Visual Design**

Regarding the visual design of the cards, E3 mentioned that he forgot the functions of each section without a constant visual reminder. (The version of the cards used for expert review does not have section headings because I assumed it should be
obvious. See Figure 3.11.) He said that he got the role of each section at the beginning. However, he tended to forget this and instead read all the sections when he used the cards.

E2 provided some suggestions from the graphic design perspective. He suggested that I remove the dashed line surrounding the picture examples on the back side (Figure 3.11). He also suggested that I make the two pictures of the same height and vertically aligned to show their relationship. This was for a more elegant and simple look.

Figure 3.11. Expert Review Version of a Tangible Card (Both Sides)

Note: The pictures are about Springboard (Antle, Corness, et al., 2009). Copyright 2009 by Alissa N. Antle. Used with permission.

How Reviewers Would Use the Cards

When asked about how they might use the cards, expert reviewers mentioned that they would use the cards to evaluate/critique a design, to refine ideas, to structure a design discussion. E1 said:

“I could see using these to help critique or interrogate an existing design during an early prototyping stage. I think the deck could be used to structure a conversation about which elements should be included, or how they are being employed. I could see coming back to
these periodically during a design process to help assess the evolution of the project.”

E4 also saw the cards as a learning tool for design students. On the other hand, three out of the four reviewers did not consider the cards a good brainstorming tool. As I briefly mentioned earlier, E3 thought the cards had too much text on them, which made them unsuitable for quick brainstorming. He also said that although the amount of information that the cards carry makes them like a learning tool, the cards may not be good medium for education. Also he did not think learning and brainstorming could be done at the same time.

3.8.3. **Expert Review: Summary**

Through the expert review, the quality of Tango Cards—my research instrument was improved. This in turn enhanced the validity of my user study because it reduced the possibility that quality issues of the cards interfered with my analysis and interpretation of user study results. For example, when participants reported later that they did not like a specific feature of the cards, I could more easily attribute it to my conscious design decisions, rather than thoughtless mistakes.

The findings of expert review also enabled me to make educated guesses about user study results, and informed me of what may worth special attention when I collected and analyzed user study data. For example, expert reviewers reported that they found some picture examples of prototypes of tangible learning games difficult to understand. Expert reviewers also generally thought the cards would be useful for evaluation, but less so for brainstorming. I consciously looked for similar themes from user study.

Finally here is a summary of major revisions that I made to the cards based on expert reviewers’ feedback and the design goals of Tango Cards:

- Fixed unclear, inaccurate wording.
- Replaced several prototype pictures with pictures from everyday life when I judged the latter was able to better communicate the specific concepts than the (available) former.
- Added (colour-coded) section headings.
After the design of Tango Cards, the next step in the thesis study was to evaluate Tango Cards to answer the research questions through a user study. The methodology behind this user study is discussed in the following chapter.
4. Research Methodology and Design

I employed a form of single-case study as my research strategy to investigate my research questions. In this chapter, I first restate my research questions and justify my choice of research strategy. Then I describe the research design, including task design, participant selection, and procedure of the user study. Data collection and analysis approach follow. I close this chapter with a discussion about the reliability and validity of the methodology.

4.1. Restatement of Research Questions

Table 4.1 lists my research question and the constructs and/or factors associated with them.

**Table 4.1. Research Questions and Constructs/Factors**

<table>
<thead>
<tr>
<th>Research Questions</th>
<th>Construct or Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.a How do designers use Tango cards in different design activities?</td>
<td>Card uses</td>
</tr>
<tr>
<td>1.b In which design activities do designers find the cards useful?</td>
<td>Design activities and phases</td>
</tr>
<tr>
<td>1.c How do the design features of Tango cards support or limit such uses?</td>
<td>Card design features</td>
</tr>
<tr>
<td>2 Are Tango Cards an effective design tool in making design knowledge about tangible learning games accessible to designers during their design process? In which ways do cards make the knowledge accessible to designers? In which situations and for whom?</td>
<td>How the card features in terms of content, presentation, and form make the knowledge accessible.</td>
</tr>
</tbody>
</table>
4.2. Justifying the Methodology and Approach

To investigate my research questions, I used a combination of observation, interview, and survey methods. It can be seen as a type of single-case study. Next I discuss why I chose this research strategy, in which (most) ways this strategy qualifies a single-case study, and in which ways it may not strictly be a case study.

According to Yin (2003), case study as a research method has a distinct advantage when a “how” and “why” question is being asked about a contemporary set of events in their real-life context; and over which the investigator has little or no control. The case of Tango Cards research justifies a single case study on the following criteria set by Yin. First, it investigated “how” and “why” questions. Second, the event of participants interacting with Tango Cards was a contemporary event. Third, the ways that participants interacted with the cards were not manipulated. They were asked to use the cards in whatever ways they wanted to complete the design tasks. Fourth, the case also entailed many interwoven factors that were difficult to disentangle (e.g., how participants used the cards and their opinions on cards are not only attributed to card design features, but also factors such as participants’ knowledge level of the domain, their experience with cards, and their work styles). Last but not least, I collected data from multiple sources: observation during the design tasks, interview, and survey to examine my research questions. I use these data in a triangulating fashion to enhance the validity of my inquiry.

On the other hand, my research may not strictly be a case study because of following reasons. First, it happened in a lab setting with recruited design students rather than in the field (e.g., in a design office). Second, the design cases were contrived rather than real project cases. Third, the duration of the design sessions (3-3.5 hours) may be shorter than real-life sessions.

However, I would also argue that although the design tasks were a bit contrived and simplified (did not include constraints of real-life projects), but they still hold ecological validity to a large degree. Also, the fact that it was conducted in the lab is more about convenience than methodology. It could have taken place just the same in a design office. For the rest of this chapter, I will discuss the design of my research and
justify its validity following the guidance and using the terms of case study literature e.g., (Yin, 2003).

I examined the use of Tango Cards in only one context, in which design students/researchers used the cards to do two design tasks. Therefore, it is a single-case study. I used this one case as the starting point to explore my research questions at an early stage. This supported me to find out what design features work well and what do not and provides “rich qualitative accounts” of how different design features can affect how users’ use and think of the cards (Zaman et al., 2012). As a result, I can formatively decide which direction to explore as next step as well as evaluate and improve the cards in this process. In addition, the amount of work of a single case also fit the scope of a master thesis.

4.3. Purpose and Criteria

As my research explores a new design space, there exists little existing knowledge upon which I can build propositions (Yin, 2003). Still, the object and purpose of the exploration, as well as the criteria by which the exploration will be judged as successful should be stated.

The object of the exploration has been stated in my research questions. The purpose of this exploration is twofold. One is to contribute the artifact of Tango Cards as a design tool for tangible learning games. A higher-lever purpose is to contribute generalizable design knowledge about how to create design tools (cards or alike) that transfer academic knowledge to design practice, with a focus on informing.

The criteria that I set to judge whether such an exploratory study achieves its goal is whether I find answers to all my research questions, and whether my research design used those recommended case study tactics (Yin, 2003) to ensure its validity.

4.4. Prototype

The final version of Tango Cards is described in section 3.4.
4.5. Participants

Twenty-four (24) students at Simon Fraser University of Surrey campus participated in the study, a pair of them for each session. These participants were recruited from the following sources: SIAT graduate students (9 participants), students from two undergraduate classes of School of Interactive Arts and Technology (SIAT) (8 participants), and SFU Game Developers Club (7 participants). All but one participant was students (undergraduate and graduate levels) of SIAT. Two of the participants that were recruited from the two undergraduate SIAT classes were also members of SFU Game Developers Club. Seven (7) participants were female and 17 were male; fifteen (15) were undergraduate students and nine (9) were graduate students. The average age of the participants was 25.8 (20-25 years old: 16 participants; 26-30 years old: 5 participants; 31-35 years old: 2 participants; and one 50+ participant).

Participants were compensated with $20 cash. For participants recruited from the two SIAT undergraduate classes, they could also choose to get course credits and $10 cash instead.

4.5.1. Identifying Target Card Users and Selecting Qualifying Participants

As tangible learning games are still being done at research level and have yet to become industry practice, I decided that the target users of Tango Cards should be research-based designers and/or senior design students (at least until the near future). Ideally participants should have experience designing for at least one of tangibles, games, or learning applications. However, it was difficult to find enough candidates in the populations I recruited from who had experience in tangible design and/or learning design. The only source of those candidates with tangible design experience was from SIAT graduate students who had taken the Tangible Computing class and I recruited five such participants. Learning design experience is even rarer among SIAT students. As a result, I decided to recruit designers with general interaction design experience and exempted the requirement for learning design experience. In the recruitment process, candidates with tangible design experience were preferred over those with only general
interaction design experience. I paired the final 24 participants so that the experience of each pair covered both tangible design (or general interaction design) and game design. Five pairs had tangible experience while the other seven pairs did not. For convenience of reference and discussion, the first five pairs will be referred to as the *expert group*, while the other seven pairs will be referred to as *novice group*. This compromise in recruitment criteria can be seen as a limitation of this study. However, in such a new and complex design space, it would be rare that designers had adequate knowledge about two or more dimensions of the design space. Again, this speaks to the need for Tango Cards. In addition, six pairs (50%) of participants had worked together or known each other before the study, and six other pairs had not.

Participants’ knowledge and experience that are relevant to this study are summarized in Table 4.2.

*Table 4.2. An Overview of Participants’ Relevant Experience*

<table>
<thead>
<tr>
<th>Knowledge and/or Experience</th>
<th>Number and Percentage of Participants that Had It</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interaction design</td>
<td>22 (91.7%)</td>
<td>From projects and/or classes</td>
</tr>
<tr>
<td>TUI design</td>
<td>5 (20.8%)</td>
<td>From the SIAT graduate level class of Tangible Computing and/or projects</td>
</tr>
<tr>
<td>Game design</td>
<td>16 (66.7%)</td>
<td>From projects, classes, and/or game research</td>
</tr>
<tr>
<td>Child learning design</td>
<td>2 (8.3%)</td>
<td>One of them was also familiar with basic learning theories</td>
</tr>
<tr>
<td>Tangible learning game</td>
<td>8 (33.3%)</td>
<td>Ten (41.7%) participants self-claimed to have experience with tangible learning games, but the description from two of them were too vague and/or wrong. All the correct answers were from graduate students who either took the Tangible Computing class or had experienced / read colleagues’ work about TUI.</td>
</tr>
</tbody>
</table>
In addition, one pair of participants (session 2) turned out to be an outlier: the participant who was accepted for her game design experience (as she self-reported to be taking a game design class) did not exhibit enough game design knowledge to carry on the game design discussion, and her partner only had general interaction design experience. Consequently, this pair was not able to complete the design tasks and produced very few ideas. I considered this pair to be unqualified and treated them as an outlier. Therefore, I removed the survey data from this pair. On the other hand, this pair represents an extreme case of the novice group. Their feedback on cards was still useful to help answer research questions and was congruent with the other novice group pairs. Therefore, I still included the qualitative data from this outlier in thematic analysis.

### 4.6. Setting

All the sessions were held in one of the group study rooms in the library area of Simon Fraser University Surrey campus (different rooms were booked for different sessions depending on their availability during the session date/time). These study rooms had capacities of 4-8 people. They were all equipped with a table, a few chairs, a whiteboard, and a camera on a tripod in the room corner. The rooms were high lit (by either natural or artificial lighting). The two participants were asked to sit in chairs by the whiteboard. Another observer who worked as my assistant sat in a chair outside the camera’s view with a laptop to take notes. Common design tools such as pens, sticky notes, index cards were provided on the table. Water and light snacks were also provided.
4.7. Design Tasks

To examine the potential of the cards in different design activities and phases, I developed two design cases that focused on different design activities and application areas. The first design case was a redesign of a web-based game *Fizzy's Balance Bots*[^6], which teaches children learn to solve algebra problems and the importance of healthy eating, to a tangible game. The redesign goal was to make the game more effective in supporting children to learn about balanced meals and nutrition knowledge. This case focused on late-stage design activity (redesign) and school subject (algebra). The second design case was about developing initial ideas for a tangible learning game that helped children understand the complexity involved in building a sustainable environment. This case focused on early-stage design activity (initial idea development) and a more general concept (sustainability). Due to the time constraint, I did not include a design case about evaluating an existing design, although the redesign case actually required participants to evaluate the old design in order to decide how to approach their new design. See Appendix E for details about the two design cases.


4.8. Procedure

Participants were first greeted and asked to introduce themselves to their study partner if they did not know each other before. Then participants were asked to sign the informed consent form. After that, participants filled out a pre-questionnaire asking some demographic questions (age, gender, education level) and their experience with interaction design, game design, design cards, and tangible learning games (see Appendix F). The questions asking interaction and game design experience are similar to the screen questions, but asked for more details. These questions aim to verify participants’ level of expertise and would also be used to investigate the RQs.

After completing the pre-questionnaire, participants were given an introduction of tangible user interfaces through a PowerPoint presentation and a video of a tangible...
system Reactable\textsuperscript{7}, which last around 10 minutes. Participants were then introduced to Tango Cards and were asked to explore the deck for five minutes. Participants were also told that the QR code on the cards was not implemented, and I could show them the linked information during the study if they wanted to check it.

After a brief introduction to the first design task, participants started to work on it. They were told that they had 40 minutes to work on this activity, followed by a 5 minute presentation. They were reminded (up to three times) to use the cards if they were observed to work without cards for a considerable amount of time. They were reminded to wrap up and prepare to present their design ideas when they had around five minutes left. In the presentation, participants were asked to not only describe their key game and tangible design ideas, but also to justify their design decisions and explain where their ideas came from. A quick impromptu interview occurred for some sessions when I needed clarifications on some design ideas and how the participants used the cards.

After a 5-minute break, participants started working on the second design task, which was structured in the same way as the first design task. Following the completion of the second design task, participants then filled out a questionnaire to rate the value of the cards in different design activities, how much they liked different sections of the cards, and the overall design and value of the cards on a 5-point Likert scale (see Appendix F). The session ended with a semi-structured group interview (see Appendix F). Questions included asking participants about their overall impression of the cards, what they liked and disliked about the cards, and whether they would used the cards in future design activities and how. Participants received their compensation at the end and were thanked for their participation. The sessions last between 3–3.5 hours. To alleviate the fatigue caused by the long session, participants had a 5-minute break between the two design cases. Snacks and water were also provided. Based on my observation of the 12 sessions, participants were highly engaged in designing games. For most sessions, I had to remind them of the remaining time so that they could finish developing their ideas in time. This suggests that fatigue may not be a problem.

\textsuperscript{7} Retrieved May 10, 2014, from http://www.reactable.com/
4.9. Pilot Study

A pilot study was conducted in September 2012 to evaluate whether the design briefs for the two design tasks were effective, whether the questionnaire and interview questions are clear, whether the amount of time needed to complete each design task was sufficient, as well as to practice and review the study protocol. A pair of SIAT graduate students (one male and one female) in their 30s participated in the pilot study. Both of them had experience in tangible design and game design. They had been familiar with my research and had provided feedback on my work, which made them unsuitable as formal participants but perfect for pilot study.

The biggest change resulted from the pilot study was the second design case. The original second design case was about evaluating the effectiveness of a tangible learning prototype *Towards Utopia* and further developing its game mechanics (the existing system had some game elements, but was not complex enough to justify a game). Both participants of the pilot study reported that the design brief was too long to read; and even after reading the brief, they still felt confused about how the real system worked. As a result, this design case was replaced with a task to develop initial ideas for a tangible learning that teaches children sustainability to better fit the design task into the limited time. One participant also suggested changing the tangible introduction video that was played at the beginning of the session as he thought the video used was not effective to introduce the TUI concept. A video of *Reactable* was used in formal sessions per his recommendation. In addition, one participant suggested that some snacks would be appreciated as the study session was long (about three hours). As a result, snacks and water were provided for the following sessions.

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4.10. Data Collection

4.10.1. Data Sources

Using multiple sources of evidence is one important data collection principle for case studies (Yin, 2003). According to Yin (2003), compared with other research strategies, case study especially needed multiple sources of evidence to support “converging lines of inquiry”. Such triangulation of data could increase the construct validity of the study. For my study, I collected data from the following sources with the help of my assistant: direct observations, interviews (semi-structured), and survey (structured using Likert scale). In addition, I photographed representative card use behaviours and the resulting card set configurations during the sessions of the design activities. Sessions of design activities were videotaped and interviews were audio recorded.

Direct Observation

My assistant and I took observational notes during the two design cases. We observed how participants used the cards, their comments on the cards when they used them, and how they worked with their partner. Video recordings were also taken. I did not transcribe or video code all the video data, but went back to check certain segments when my assistant and I found interesting data points worth detailed investigation in the observational notes. Accordingly, I transcribed certain video segments and cited them in the Results chapter. I mainly used an “open” approach to collect observational data. That is, I captured all the data points that I considered relevant to my research questions. Meanwhile, findings of previous card studies as well as expert review gave me some directions on what especially to look for.

Interview

I conducted group interview with the pairs at the end of each session. I asked questions such as their overall impression of the cards, what they liked and disliked about the cards, and whether they would used the cards in future design activities and how (see Appendix F). The interview data was collected to gain insights about participants’ opinion of the cards. Their self-report on how they used and how they might
use the cards corroborated their behaviour observed, thus enabling me to make stronger
claims. For some sessions, I also conducted spontaneous mini interviews right after
participants’ presentation of their design, to verify some important data points.

Survey

Tango Cards study included pre- and post- questionnaires. Pre-questionnaire
collected demographic information and participants’ experience with interaction design,
/game design, design cards, and tangible learning games. Post-questionnaire involved
Likert-scale questions asking participants to rate how valuable they thought the cards
were in different design activities, how much they liked different sections of the cards,
and the overall design and value of the cards. The pre-questionnaire survey data
provided context and useful handles for interpreting “main” study data and gaining
insight. The survey data from post-questionnaire, on the other hand, provided another
source for answering the research questions. See Appendix F for the survey questions.

Table 4.3 summarizes how I collected and analyzed data from a variety of
sources to answer each research question. The abbreviation for each data type is listed
below:

- IQ – Interview questions
- SQ – Survey questions
- OB – Observation

<table>
<thead>
<tr>
<th>Research Question</th>
<th>Data Source</th>
<th>Data Specifics</th>
<th>Analysis Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.a How do designers use Tango cards in different design activities?</td>
<td>Observation; Interview</td>
<td>Both expected and emerging card uses; Participants’ comments on their card use; IQ 7</td>
<td>Thematic analysis</td>
</tr>
<tr>
<td>1.b In which design activities do designers find the cards useful?</td>
<td>Interview; Survey; Observation</td>
<td>Data collected to address RQ 1.a; IQ 7; SQ 1</td>
<td>Thematic analysis; Descriptive statistics</td>
</tr>
<tr>
<td>1.c How do the design features (e.g., content,</td>
<td>Interview; Survey;</td>
<td>IQ 2, 3; Data collected to</td>
<td>Thematic analysis; Descriptive statistics</td>
</tr>
</tbody>
</table>
In the following sections, I provide more details about how I collected data for each RQ.

4.10.2.  **RQ 1.a: How do designers use Tango Cards in different design activities?**

For RQ 1.a, I looked at card uses by participants that either contributed to the design outcome, or ease or speeded up the design process. I collected data about how designers used Tango Cards in different design activities in a combination of open and structured approaches. My assistant and I looked for emerging behavioural patterns and their comments on how they used the cards during the observation and interview (open approach). Meanwhile, in previous studies about designing cards as a design tool, researchers have reported some behavioural patterns of designers. I selected those behavioural patterns that I considered “transferrable” and looked for them during the observation (structured approach). I judged whether a behavioural pattern was transferred based on whether the pattern could be attributed to some design features that were shared with or similar to Tango Cards. For example, I included the behavioural pattern of using cards to “orienting team members” that was reported by Bekker and Antle (2011) and Hornecker (2010) in my observational framework because this behavioural pattern was mainly attributed to the physical form of cards and thus should be enabled by Tango Cards too. On the other hand, I did not include the behavioural
pattern of “comparing information” reported by DSD cards (Bekker & Antle, 2011) because this was attributed to the design feature of different age categories of DSD cards, which Tango Cards do not have. Findings from my expert review also gave me ideas about what to look for.

In the post-study interview, participants were asked the question (IQ 7) “Would you use the cards in future design activities? If yes, how would you use them? If not, why not?” Participants’ response to this question served as a second data source for this question. Participants sometimes commented on their card use when answering other questions (such as their overall impression of the cards) and such data was used too.

4.10.3. **RQ 1.b: In which design activities do designers find the cards useful?**

By **useful**, I mean designers show considerable amount of quality uses of cards in the design activities, and that they find the cards help their design process and/or outcome. I collected data for RQ 1.b in three ways. First data source is the data collected for RQ 1.a (as discussed in more detail in section 4.11.4). The second source was a survey question collecting participants’ rating of the value of the cards for different design activities on a 5-point Likert scale (SQ 1). The third source was their response to the post-study interview question probing whether they would use the cards in future design activities and how (IQ 7). Participants’ responses to other questions (such as their overall impression of the cards) that were relevant to this RQ were used too.

4.10.4. **RQ 1.c: How do the specific design features of Tango Cards (e.g., presentation, form, content) support or limit such uses?**

It is likely that in most situations it was holistic design features rather than an isolated design feature that contributed to a specific card use behavioural and/or its value in a design activity/phase. Nonetheless, I think it was meaningful to identify which card design feature or a combination of several features particularly support or limit a specific card use. The data to address RQ 1.c was from three sources. First, I used interview questions that asked participants what they liked and disliked the most about the cards, and the top three cards they liked and disliked the most and why. The part of
their comments that addressed card features served as the data for this RQ. Again, participants’ responses to other interview questions that were relevant to this RQ were used too. Second, I used the data that I collected to address RQ 1.a. Third, in the post-questionnaire, participants were asked to rate how they liked each section of the cards, and the overall visual design of the cards on a 5-point Likert scale.

4.10.5. **RQ 2: Are Tango Cards an effective design tool in making design knowledge about tangible learning games accessible to designers during their design process?**

In their DSD cards study, Bekker and Antle (2011) put accessible into the context of DSD study: "...make theoretical knowledge about children’s needs, skills and abilities accessible to designers." In a similar vein, the goal of the Tango Cards is to make existing academic knowledge about designing tangibles and games for learning more accessible to designers during their design process. I define accessibility as how well the design knowledge represented by the Tango Cards is within designers’ reach both physically and cognitively. Is the knowledge easy to understand? Is the knowledge usable and easy to apply? Is the knowledge easy to access physically? Accordingly, effectiveness in this context evaluates to what extent Tango Cards can help designers in their design process and affect their outcome in final design by making the design knowledge accessible to them in a variety of ways.

To answer this RQ and its sub-RQs, I synthesize the findings of RQ 1.a, 1.b, 1.c. Interview data that is relevant to this RQ was also used. Lastly, participants were asked to rate the overall usefulness of the cards in the post-questionnaire (SQ 4). Although the “useful” is a broader concept than “accessible”, this rating could be a useful data point. After all, if participants do not consider the cards useful at all, the chance that the cards do a good job at making the knowledge accessible to designers is very small.

4.11. **Data Analysis**

I analyzed qualitative data (observational and interview data) using thematic analysis, and I analyze survey data (Likert scale) using descriptive statistics. A summary
of data collection and analysis methods that I used for research questions can be found in Table 4.3.

As I applied the same and holistic thematic analysis procedure for the qualitative data (observational and interview data) for all the research questions, I described the process in the following section and will not repeat the description for the analysis methods for each research question.

### 4.11.1. Holistic Thematic Analysis for Qualitative Data

**Defining ‘Code’**

Before I describe my data analysis approach, I will first explain an important concept in qualitative research: *code*. Saldaña (2013) provided an excellent definition of code in her book *The Coding Manual For Qualitative Researchers*:

A code in qualitative inquiry is most often a word or short phrase that symbolically assigns a summative, salient, essence-capturing, and/or evocative attribute for a portion of language-based or visual data. The data can consist of interview transcripts, participant observation field notes, journals, documents, literature, artifacts, photographs, video, websites, e-mail correspondence, and so on. The portion of data to be coded during First Cycle coding processes can range in magnitude from a single word to a full sentence to an entire page of text to a stream of moving images. In Second Cycle coding processes, the portions coded can be the exact same units, longer passages of text, and even a reconfiguration of the codes themselves developed thus far. Just as a title represents and captures a book or film or poem’s primary content and essence, so does a code represent and capture a datum’s primary content and essence.

In my thesis, any description or discussion about codes aligns well with Saldaña’s definition.

I coded the qualitative data for each session holistically rather than separately for different research questions. I used the coding methods and process documented in (Saldaña, 2013) to guide my coding process, which is described below. As a preparation for coding the data, I transcribed the paper notes taken by my assistant and myself during observation and interview to digital notes. I took paper notes during the study as it
was more convenient for me as the facilitator and was less intrusive. My assistant took
digital notes for most sessions as it was faster and he was able to catch more details.
Then I printed out all the notes and read the data of all the sessions for a couple of times
with the research questions in mind, to get a feel of the overall data and develop an
initial idea of the potential themes. After that I started coding the data for the research
questions.

The observational data was primarily for RQ 1.a. I assigned codes to emerging
card use behaviours as well as expected card use behaviours from previous studies. At
the same time, I kept an eye on participants' behaviours and comments that were related
to other research questions (such as card features and value) and assigned codes to
these data.

For the interview data, although most interview questions have specific research
questions that they aim to investigate (see Table 4.3), I was aware of the open nature of
my semi-structured interview. Accordingly, I looked for data relevant to a certain
construct/factor not only in the response to the corresponding interview questions, but
also through the interview data.

I wrote codes in the margin of the paper notes. After I coded the data for a few
sessions, I started to see repeated patterns and apply codes from earlier sessions to
later sessions. I also started to notice codes that were “too similar” and/or embrace other
codes. I marked some of such codes but I waited until I finished coding all the sessions
for the first pass to modify the codes. After I finished coding all the sessions, I
transferred the codes to an Excel sheet, with one row for the data for each session, one
column for each code. If a session had data for a certain code, I typed in the
 correspon ding spreadsheet cell the abbreviation of the data type (OB for observational
data, and IN for interview data). If the instance was representative and I wanted to use it
as an example in the results, I also noted down in which design task the instance was
found, in which part of the task (design activity, presentation, or interview), by whom
(both my assistant and myself, or one of us), and the time stamp (if it was found during
the design tasks). Instances that were identified by both of us were given more weight
than instances that were found by only one of us.
I reviewed the resulting codes and code distribution among sessions. I refined the codes to make sure that the codes were distinct. This was an iterative process. In my practice, when the codes were still half-baked, I moved on to affinity diagramming (Beyer & Holtzblatt, 1997) to further tidy up the codes because it is more flexible and efficient to move and group codes physically, and it is much easier to find relationship between themes by looking at color-coded sticky notes than reading an Excel sheet. For each research question, I wrote all the codes that I assigned to its data on sticky notes, one code for each sticky note. I noted down the sessions that included the code on the sticky note too. Through iteratively moving and grouping codes, I dug deeper into the data and further adjusted the codes. Some codes were subsumed, revised, or dropped. Some groups/categories were rearranged and new groups sometimes emerged. For example, for RQ 1.c what card design features support or limit card design features, I further categorized its codes by the three aspects of card design: content, presentation, and form. For each aspect, I further categorized the codes by “what participants liked”, “what participants do not like”, and “what suggestions for improvements participants give”. 

Figure 4.1. Affinity Diagram
Figure 4.1 shows my affinity diagramming results. The final results of the affinity diagramming were patterns (i.e., participants' behaviour or comments that were very similar and/or shared some characteristics (Saldaña, 2013)) for each research question, grouped by theme.

4.11.2. **Descriptive Statistics for Survey Data**

I used descriptive statistics (mean and standard deviation) to analyze the survey data on a 5-point Likert scale. Mean and standard deviation are two of the most commonly used measures to summarize the characteristics (i.e., central tendency and variance) of data. On the other hand, although mean and standard deviation are used by many researchers to analyze Likert scale data, it has also been cautioned that Likert scale data actually do not meet assumptions behind using mean and standard deviation as measures. Likert scales are ordinal not interval. They are nonlinear due to subjective interpretations of participants as well as participants’ tendency to cluster toward the middle or extremes of the scales (Gardner & Martin, 2007). However, this should not be a big concern for my case. I used mean and standard deviation just to give a general idea of the distributions of different Likert data scales. I did not intend to run inferential statistics to test hypotheses. Therefore, the convenience of using mean and standard deviation outweighed the risks.

4.11.3. **RQ 1.a: How do designers use Tango Cards in different design activities?**

I used thematic analysis to analyze the observational and interview data for RQ 1.a.

4.11.4. **RQ 1.b: In which design activities do designers find the cards useful?**

I used thematic analysis to analyze the qualitative data that were collected for answering RQ 1.a and reused for addressing RQ 1.b, as well as additional interview data for RQ 1.b. I use descriptive statistics to analyze survey data.
I addressed RQ 1.b by analyzing the study data as stated above and making *inferences* from them. Due to time constraints and limitations on scope, I only directly evaluated two design activities in the user study (one of redesigning a computer learning game to a tangible learning game, and the other of initial concept development of a tangible collaborative sustainability game). Both involved early concept development, although the redesign case was more narrowly defined since the context and main idea were already determined. (The 45-minute duration of each session would only allow participants to finish the first round of ideation.) Thus, I could only make direct claims about the value of the cards in the early stage of design process from my data. I made inference about the value of cards in later-stage design activities from some card uses that participants demonstrated in the two design cases as well as from the interview and questionnaire data. The claims based on inference were less conclusive, but they were still grounded in data.

4.11.5. **RQ 1.c: How do the specific design features of Tango Cards (e.g., presentation, form, content) support or limit such uses?**

I used thematic analysis to analyze the interview data for RQ 1.c to see what participants liked and disliked about the cards and the reasons behind their responses. I also drew on the data collected for answering RQ 1.a, investigating the links between the way participants used the cards and card features. Again, I used descriptive statistics (mean and standard deviation) to analyze the corresponding survey data. I looked at the three elements of card design: content, presentation, and form. For each element, I examined what worked well (support card uses), what did not work well (limit card uses), and participants’ suggestions for improvements.

4.11.6. **RQ 2: Are Tango Cards an effective design tool in making design knowledge about tangible learning games accessible to designers during their design process?**

I synthesized the findings of RQ 1.a, 1.b, 1.c and made inference and interpretation from them to answer RQ 2. I used thematic analysis to analyze additional
interview data. I used descriptive statistics (mean and standard deviation) to analyze the related survey data.

4.12. Reliability and Validity

Yin (2003) discussed the four logical tests (construct validity, internal validity, external validity, and reliability) for judging the quality of case study design (and empirical social research in general) as well as the recommended tactics for dealing with these tests for case study research. I used a few of these tactics for my thesis. Here I describe how I applied these tactics during data collection, analysis, and presentation of the results.

4.12.1. Reliability

Reliability concerns about “mak[ing] as many steps as operational as possible” so that later investigators can easily repeat the case study (Yin, 2003). First I used a case study protocol. Although my protocol does not strictly follow the structure that Yin suggested (2003, p. 69), my thesis proposal and study protocol together covered all the elements of a case study protocol except that I did not have a complete guide for the case study report. I also adjusted my study protocol after running a pilot study as mentioned earlier. Second, I developed and maintained a case study database to store all the raw data so that other investigators can review the raw data that are not reported in my thesis due to space constraints. Finally, I also maintain a chain of evidence to enable other investigators to trace from my conclusions to initial research questions and vice versa. Especially, I made sufficient, rich, detailed citations to the raw data in the Results chapter of my thesis.

4.12.2. Construct Validity

To ensure construct validity, first operational measures should be established to collect data; second, the measures must collect the right data for the research problems to be investigated (Yin, 2003). I collected data from multiple sources (observation, interview, and survey) to develop “converging lines of inquiry” (Yin, 2003). The
triangulation and corroboration among different sources of data enhanced construct validity. In addition, I established “a chain of evidence” (Yin, 2003). That is, I made sure readers were able to trace the steps of my case study process in both directions. They could understand how I reached my ultimate conclusion from the initial research questions, and vice versa. This tactic increased the construct validity and reliability of my study. The last tactic was that two researchers (my assistant and myself) collected observational and interview data together but independently.

4.12.3. **Internal Validity**

As Yin (2003) pointed out, *internal validity* only applied to explanatory or causal studies. Yet Yin also stated that case study extended internal validity to the broader problem of making inference, which my research also involved (especially for RQ 1.b). Accordingly, I tried to address all the possible rival explanations when I analyzed the data, as shown in the Results chapter. Moreover, as I mentioned in 0, I conducted expert review before user study to improve the quality of the research instrument (the cards). This reduced the possibility that quality issues with the cards confounded my analysis of user study results.

4.12.4. **External Validity**

*External validity* deals with “whether a study’s findings are generalizable beyond the immediate case study” (Yin, 2003). Case studies aim towards *analytical generalization* rather than *statistical generalization*. Yin (2003) argued that when possible multiple-case design should be used because replicating the findings in other cases could greatly expand the external generalizability of the findings. Although Tango Cards study is by itself a single-case study, I used design knowledge produced by previous card research to guide the design of my research instrument (i.e., Tango Cards) and to inform my research design. The part of results of Tango Cards study that echo with those of previous card research has made that part of design knowledge more robust. I also tried to aggregate the results of all the existing relevant card studies (that is, design cards as a knowledge transfer vehicle between scholarly design research and design practice), as well as to abstract this design knowledge to make it generalizable to
other design spaces. I believe all these strategies have helped improve the external validity of my research. On the other hand, this knowledge that I produced from Tango Cards study needs to be tested in more cases before strong claims can be made about it.

In the next chapter, I report the findings of the user study and my analysis of the results.
5. Results

In this chapter, I report the results of the study, organized by research question. For the findings of each research question, I first report themes that emerged from qualitative data. I illustrate themes with “rich, thick” examples from participants’ quotes and observational data. Survey data follows if available, presented in descriptive statistics. I also present my interpretations of the qualitative and quantitative results.

5.1. RQ 1.a: How do designers use Tango Cards in different design activities?

I identified the following themes regarding to how designers used the cards in the two design cases (Deng, Antle & Neustaedter, 2014):

- Formative evaluation (new)
- Leverage card form to externalize design ideas and critique (new)
- Getting inspiration when ideation gets unproductive (Bekker & Antle, 2011; Hornecker, 2010; Lucero & Arrasvuori, 2010)
- Jumping off ideation (Halskov & Dalsgård, 2006; Hornecker, 2010)
- As communication shorthand (Halskov & Dalsgård, 2006; Lucero & Arrasvuori, 2010)

Of these themes, the use of cards in formative evaluation is most prominent and has not been reported by previous studies. The advanced use of the card form to externalize design rationale and analysis is new too. Previous card works have mentioned the other three themes in passing, but did not delve into details. In this section, I first present a card use scenario extracted from session 10 to demonstrate a variety of card uses and how cards fit within the study’s larger design process. Then I will describe each card use theme, and provide concrete examples for each use.
I want to point out that both the uses of formative evaluation and returning to cards for inspiration were facilitated by the information on the cards. Accordingly, at a deeper level, Tango Cards informed designers in both situations. I will elaborate on this in 5.1.2 and 5.1.4 when I describe these two card uses.

### 5.1.1. A Card Use Scenario

At the beginning of the first design case, while looking at the cards put on the table, P19 proposed using fruit-shaped control as the tangible element and claimed that she got the idea from the *Coherent Mapping* card (she soon realized that her idea was actually about *Linking through Metaphor*). P19 also proposed an idea from the *Intrinsic Rewards* card. From there, they moved their ideation to white board and continued generating ideas without cards. After creating some ideas, P20 suggested, “Let us see what we have.” They returned to the cards on the table and started to review their ideas against cards. “Rewards?” as they checked the *Intrinsic Rewards* card. “Yes.” The *Feedback as Scaffold* card reminded them that they had not developed any reward mechanics. They went on to develop reward ideas, and then returned to cards to check other design aspects.

“*Pleasantly Frustrating*?” “I think we got it.”

“*Pause for Reflection*?” “For sure!” said both of them.

"*Thinking with Hand*?" "Yes."

“*Multiple Representations*?” “Yes.”

"*Dynamic Exploration*" “Yes.”

When they saw *Simplified System*, after some initial hesitation and thinking, they realized that their game could have multiple levels with the entry level as a “simplified system”. They went on to develop the game mechanics for other levels. Finally, the *Work Together* card reminded P19 that their game actually could be a multiple player game! “They can play together!” claimed P19. They went on to develop collaboration ideas; for example, each player controls a robot and they have to exchange foods to achieve balance meals.
As shown in the scenario, participants used cards to kick off their discussion. Cards enabled them to formatively evaluate their ideas. Cards guided them in developing and/or fleshing out ideas, reminding them of perspectives they would otherwise neglect. The cards also served as physical reference and common vocabulary to help them reach shared understanding.

5.1.2. Formatively Evaluation

Formative evaluation—evaluating design ideas along the way as they were being developed, is a new use and the most prominent card use that I found. I observed participants checking the information on the cards from time to time to formatively evaluate the concepts that they had developed. The guidelines on the cards either confirmed that they were on the right track, or pointed them to the right direction, or reminded them of something else missing from their ideas. Sometimes participants went to the cards for formative evaluation after they had developed some game ideas without the cards, as described in the previous usage scenario. Sometimes they reached for cards right after they generated an idea, possibly with specific cards on mind as illustrated below. Examples of both uses are described below.

In the first design case (redesigning a computer learning game to a tangible game) of session 11, after the ideation went on for almost a third of the way through the
session and when P21 and P22 had proposed a few game ideas, P21 said: "Let us take a look at these (the cards)." He grabbed some cards from the table. "We are good on this," he said to the Coherent Mapping card. P22 pointed to Integrating Content and Play card and said, "We are good on this too... because we are trying to teach them about balance..." "This is what we are missing," P21 showed the Codependent Access Point to P22. He soon also realized that the game still missed the collaboration aspect as he checked the Working Together card. In this way, the cards guided their ideation process and enabled them to formatively evaluate their design along the way, confirming what has been done right and what was still missing.

As an example of participants reaching for cards right after an idea, in the first design case, P21 and P22 were discussing the game mechanics of where the (food) items should be placed when a new level of the game started. The idea they had at that point was to have the food items stay where they were left in the last round. However, they were not sure whether this was good. "You know what," said P21, "I was just looking at this one here," as he picked up the Dynamic Exploration card and read the design consideration part, ‘Can users adapt their ideas through configuring and reconfiguring the tangible objects in the space?’ Is there another card about taking a pause for reflection or something?” He looked for the Pause for Reflection card. P22 helped him find it. P21 checked the card and commented, “It might be a good idea to force players to rearrange the starting positions... the game won't get started until you put everything to where it is supposed to be... set up the table...like setting up a chess board...” So they approved their idea, as it was good for players to explore their idea and reflect on it according to the Pause for Reflection and Dynamic Exploration cards. In the interview right after the first design task, P21 explicitly mentioned how the Pause for Reflection card assured them that they were on the right track.

Indeed, as P24 of session 12 spontaneously remarked on the value of the cards during the second design case when he looked for cards to confirm his ideas: “This is when I get to these (cards)... so that all these weird floating ideas can be grounded in some kind of context...”
5.1.3. **Leveraging Card Form**

As expected, I observed many instances where participants did simple sorting and grouping of cards (see Figure 5.1, left) as a way to decide which cards were relevant to their design problem, and to bookmark discussion ideas (Bekker & Antle, 2011; Hornecker, 2010; Lucero & Arrasvuori, 2010). Moreover, I saw more “advanced” arrangement and manipulation of cards in two pairs, as a way to externalize their design idea or analysis of the old design idea, as described below.

![Figure 5.2. Using Cards to Externalize Analysis of Old Design](image)

P17 and P18 of session 9 approached the two design activities in a very systematic way. In the second design case of initial ideation of a TUI sustainability game, they first sorted through cards and selected those they decided relevant to the game topic. They further categorized these cards based on the role that they wanted the concept on the card to assume in their game idea and labeled them using sticky notes. For example, they picked *Working Together* and *Dynamic Exploration* and labeled it "Possible game play". They selected the *Simplified Actions* card and labeled it "Technical Aspects". The cards of *Intrinsic Rewards*, *Well-Ordered Problem*, *Multiple Representations*, and *Identity* were labeled “Characteristics”. As they sorted through the cards, they explained to each other why a specific card should be included. P17 also noted important design ideas on an index card. When they finished developing their game ideas, they reviewed their design against the cards.
In the first design case of redesigning a web-based learning game to a tangible learning game, P17 and P18 used cards together with sticky notes to externalize their analysis of the old design (Figure 5.2). For example, they put a sticky note with “algebra” on it onto the Linking through Metaphor card, meaning that they believed the way the old game taught algebra incorporated the “linking through metaphor” idea. They put another sticky note with “dancing” on it on the Intrinsic Reward card because they considered the robot dancing at the end of each round when kids successfully balanced the meals of robots an intrinsic reward.

Unlike P17 and P18 of session 9, who used the cards to “outline” their game idea before they start to develop concrete ideas, P11 and P12 of session 6 allowed their ideas to emerge and evolve in their discussion and in simple grouping and sorting the cards. The advanced use only happened near the end. When their discussion was drawing to a close, P11 started sorting the cards to externalize the rationale behind their game idea. He verbalized the rationale while sorting the cards.

Figure 5.3. Using Cards to Externalize Design Ideas
"...So at the beginning we have Low Risk Exploration and Simplified System. We "Think with Hands" all the time," as he threw the Thinking with Hand card to a separate row at the top.

“This mode (balance meal mode) involves Working Together.”

“The whole game involves Multiple Modalities, visual display, food pieces they play together...”

“Recreate a meal mode has pause (referring to the Pause for Reflection card).”

After a series of sorting and grouping, he finally said,

"I think that is all covered."

The final card arrangement is shown in Figure 5.3, P11 explained that their redesign consisted of three modes: free exploration mode, balance meal mode, and recreate meal mode, with a pile of cards for each mode. The top row of cards applies to all the three modes. The deck of cards on the left was considered irrelevant.

Next I will describe three uses that previous card research has reported on.

5.1.4. Getting New Inspiration When Ideation Gets Unproductive

Participants turned to cards for new inspiration when their discussion became unproductive. The information on the cards triggered new ideas, or refined and fleshed out their existing ideas. In the second design case (initial ideation of a tangible, collaborative game of sustainability) of session 12, P23 and P24 returned to cards after some ideation on the whiteboard without the cards. P23 picked up Related Skills to Goals, and decided it was not relevant as the skills involved in their design was simply lifting “walls”. He picked up Pleasantly Frustrating, repeated the title name, and said, “Hopefully (our design has this).” Looking at Pause for Reflection, P24 commented, "Unfortunately the game doesn't have this." "It has the pause button,” P23 refuted. “Or we can use the button to adjust difficulty and change how fast the time goes,” P23 proposed a new idea and went on to flesh out the idea. P24 built on this and proposed using a tangible slider to change how fast the time goes. As shown in the example above, the use of cards for new inspiration was intertwined with formative evaluation. This intertwinement is consistent with the fluid nature of design discussion. Designers can go
to cards for evaluation, and what the cards tell them are missing from their idea could trigger their ideation. Designers can also reach cards for inspiration, and then some cards provoke their reflection and evaluation on existing ideas. In both uses, the information on the cards guides their design discussion. P23 stated in the interview:

“...Very useful...more for brainstorming...made it very fast. Instead of sort of staring at a design and wondering: ‘oh, what can go wrong and how could I improve this,’ this huge bank of ideas, criticisms, or heuristics I could apply to my design. Just go ‘yeah, totally matched that’ or ‘no, doesn't really match that... and that would just stimulate more changes.’

Note: As I will clarify in section 5.2.1, what P23 meant by “brainstorming” is initial ideation.

In the interview Q1, P13 commented: “We pull out some cards, and we know which direction to think... I know if this card wasn't [hadn't been] here, Alex (P14) won't be [would not have been] talking about at some point this city will be look like New York (their game idea).” P10 of session 5 also stated that he would use the cards as “a reference when [you] get lost in the design phase” when probed about post interview question 7.

5.1.5. Ideation Jumping-Off Point

I saw various instances where participants used cards to develop the first few “seed ideas”. For example, at the beginning of the first design case in session 6, both participants looked at the cards laid in a matrix on the table. Then P11 said, “Since the game uses this new interface (the tangible user interface), seems like there should be some testing mode to start with? We have this idea of Low Risk Exploration. Maybe the game could start with using the food thing and seeing the lights up in the centre? …so recognize this is some kind of food?” Following the first idea and pointing to the Simplified System card, P12 proposed: "The game could start with a simplified version of it..." P11 built on this and brought up the idea of putting on a food item and the game giving some feedback as response. From there, they further developed the idea of having an information area on the table top to show the related nutrition information in color dots when a food item is placed.
When being asked about his overall impression of the cards (interview question 1), P8 expressed that one of the most challenging aspects of game design was to come up with a novel idea “from vacuum”. He thought the cards provided a “visual kick-off” when you had a raw idea but not many details.

5.1.6. Common Vocabulary and Communication Shorthand

I observed in many sessions that participants mentioned the concepts on the cards in their discussion, either when they looked at the cards or they recalled the concepts without cards. This use was often seen simultaneously with the use of validating design ideas. During the first design case of session 11, P21 and P22 came up with the idea that it would not count as a move until the player put down the tangible token, and before that the players can explore and check the consequence of their move in the “information area” (sandbox area). Then P21 realized this idea actually took the unique advantage of TUI; that is, supporting physical manipulation and exploration. He also recalled that there was a card about this idea. He found the card and said, “It is Low Risk Exploration.” P22 went on to apply this concept to critique the old game that they were asked to redesign, “This one is not a Low-Risk Exploration because every move counts.” A little later as they discussed about another “trade food to achieve balance” idea, P22 argued that their idea of forcing children to trade resources to build their individual sustainable communities was good for kids to learn from each other. (“If one kid gets it but other kids don't, the kid who got it can explain why he doesn't want to trade the item.”) P21 agreed, "Yeah, this is a kind of sharing. We have this one—Shared Understanding …"

As shown in the examples above, cards (mostly titles) were used to as shorthand to create shared understanding of a concept and to bring in an authoritative voice. This speeded up their discussion.

In the post-interview of session 4, when asked about their overall impression of the cards (Q1), P8 commented: "I think it is a shorthand for what you are talking about…becomes easier to throw it around in development meetings…shared vocabulary in a meeting…instead of spending 20 minutes explaining what it means…” In response
to the same question, P14 stated that they “can point to it to get a shared vocabulary” and P13 added that the cards enabled them to “have specific discussion” and “use more complex vocabulary because the cards are right in front of us.”

5.2. RQ 1.b: In which design activities do designers find the cards useful?

As I mentioned in 4.11.4, I make direct claims about the value of the cards in early concept development; and I make interferences about the value of the cards in later-stage design activities from some card uses that participants demonstrated in the two design cases as well as from the interview and questionnaire data. Due to the iterative, fluid nature of design process, a design activity is not strictly limited to a single phase and could happen throughout the design process (to add – argument from strong concepts). For example, evaluation is not limited to later phases. As described in section 5.1.2, participants used the cards to formatively evaluate their design in early ideation. Similarly although ideation is most common in the early design phase, it can also happen in later phases when designers get inspirations or want to pursue a new direction after some evaluation.

Based on my findings, I suggest that cards are useful for the following design activities (roughly mapped to design stages in design process for convenience):

- Early concept development
- Formative evaluation (new)
- Summative evaluation (new)
- Iterative refinement of ideas

The value of the cards as a learning tool requires further examination.

Next I will describe how cards can be useful in each of these design activities.
5.2.1. Early Concept Development (after an initial concept is formed)

A variety of card uses as discussed in section 5.1 provide direct evidence that cards are useful in initial concept development, during which designers develop their first complete idea of the design task. One significant value of the cards in this phase is to guide design discussion by supporting, validating and evaluating ideas and providing inspiration, with the knowledge they carried.

Study data also suggests that participants did not find the cards that useful for developing an initial concept from scratch to kick off ideation. P8 remarked: “Really good for brainstorming session when you just come up with a raw idea and you don't have a lot details yet. You need that inspiration and visual kick-off” (interview Q1). In the same vein, P23 stated that an initial idea was needed before starting using cards to flesh out and/or refine the idea in his response to interview Q7.

In particular, some participants commented that they preferred generating ideas on their own and then going to cards for confirmation and evaluation, rather than generating ideas from the cards during the early concept development. P19 and P20 of S10, P21 and P22 of S11, and P24 all stated in the post interview and/or the mini-interview right after their design activities that they found the cards very useful for validating, refining, and evolving ideas; but less useful for “brainstorming”, as with P21 remarked right after design case 1:

"It is not like I look at the cards and at some point "I got it". It like I was thinking about something, the card either says “hey it is a good idea,” or force to evolve that idea... some cards gave me the idea to refine... never was like a direct inspiration...like iteration of ideas...”

His partner P22 was with him and added:

"[The cards] make me feel better about the idea. I like this way. [They] help validation, iteration rather than inspiration... As a designer, I don't like to be told what to do. I like creative control over my ideas, but I like validating my ideas, where my idea were from / backed up by theory."
Regarding why they did not find the cards as good for direct inspiration, P21 said the information on the cards were very specific and lacked the breadth and connection for inspiration. Providing inspiration was not the focus of the Tango Cards after all.

“Brainstorming”

My investigation into cards’ value in ideation also revealed that participants had different perceptions as to what brainstorming entailed. This inconsistency had puzzled me when I first got the data and made me believe that they have conflicting opinions on cards’ value in ideation. After examining their comments in a large context, I realized for some of them, brainstorming equalled to the duration of whole initial concept development as I defined above; for example, P8’s use of brainstorming as quoted above (“Really good for brainstorming session when you…”). For some others, brainstorming meant developing the very beginning (seed) idea from scratch.

This interesting inconsistent use of terminology indicates a lack of shared understanding of some basic design terms and/or lack of a set of specific design vocabulary to address such nuances. This could cause confusion and misunderstanding as reported above.

5.2.2. **Formative and Summative Evaluation**

As discussed in section 5.1, participants did impromptu, formative evaluations during design discussion. When they interacted with the cards, they purposefully or spontaneously checked the ideas they had developed against the concepts on the cards. The cards confirmed whether they were on the right track, or reminded them of some important concepts that their design was missing. Moreover, in answers to interview question 7, P9 said he would use the cards to review a prototype, "yes, yes, yes... in ad-hoc evaluation...I was already starting to...” P23 also mentioned the cards acted as “heuristics”. From all these, I infer that the cards would also be useful for dedicated/summative evaluation sessions, for both self-evaluation by designers or group evaluation.
5.2.3. **Iterative Refinement of Ideas**

Although the majority of ideas developed in most sessions during the two design cases were still at a general level and required elaboration and refinement, in several sessions, participants showed signs of developing concrete ideas—ideas that involve more specific mechanism and details. For example, from the *Pause for Reflection* card, P23 and P24 developed the idea of enabling players to use a tangible slider to change how fast the time goes and game difficulty level. P21 commented: “...some cards gave me the idea to refine.” P23 said cards accelerated their refinement. From these data, I suggest that cards may also be valuable for fostering idea refinement and elaboration.

5.2.4. **As a “Learning-in-Design” Tool**

The value of the cards as a “learning-in-design” tool was not specifically evaluated in the two design cases. The 45-minute time constraint did not provide designers with much opportunity to peruse the cards. Despite this, P8 and P24 made explicit positive remarks about learning from cards. P8 commented that although he had played a lot of games, he did not know the game theories behind and how to apply them. “I learned a lot (from the cards) in terms of the game that played in the past and have a way to ground them, reuse and apply them in future game design.” However, I received negative comments on the learning value of cards too. P11 argued that “the power of small cardboard is as a reminder for shared communication language and shared physical things you can point at and move around, and the role as a learning tool is at odds with such values as it requires more information.” He ventured "something in between doesn't mean anything."

In post-questionnaire question 1, participants were asked to rate the value of the cards as a learning tool. The mean is 3.5, with a standard deviation of 1.0.

The value of the cards as a learning-in-design tool requires further definite evidence.
5.2.5. **Value of Cards in Different Design Activities**

Participants were asked to rate the cards’ value in different design activities/phases on a 5-point Likert scale in the post-questionnaire (Q1), with 5 being most useful. The average and standard deviation for each design activity is shown in Figure 5.4. The standard deviations for the rating for each design activities are: 1.3 (brainstorming), 1.3 (develop concrete ideas), 1.1 (redesign), 1.0 (evaluation), and 1.0 (learning tool).

![Average Rating of Cards’ Value in Different Design Activities](image)

**Figure 5.4. Average Rating of Cards’ Value in Different Design Activities**

One limitation of this survey question is that participants had different conceptions about brainstorming, as I have discussed in 5.2.1. For some participants, brainstorming lasted the whole duration of the two design activities of concept development. For others, brainstorming meant developing the very first few ideas from scratch. Moreover, “developing concrete ideas” and “redesign” overlaps to some degree in that redesign usually starts with a clear goal and constraints from old design and thus it involves more concrete idea development. Nonetheless, the result that redesign (actually means ideation with a clear goal and constraints) and evaluation were rated highest with relatively low standard deviation aligns with the qualitative results discussed earlier.
5.2.6. RQ 1.b Final Words

From the data and discussion above, I suggest that Tango Cards are more useful after the designers have a “seed” concept. Then the cards can guide them in iteratively generating, refining, fleshing out, and evaluating ideas. Some designers might prefer developing ideas on their own and then using cards to validate their ideas, while others might continue developing further ideas using the cards. The value of Tango Cards as a learning and research tool requires further investigation.

This resonates with expert reviewer E1’s comment that I reported in 3.8.2.

“I could see using these to help critique or interrogate an existing design during an early prototyping stage. I think the deck could be used to structure a conversation about which elements should be included, or how they are being employed. I could see coming back to these periodically during a design process to help assess the evolution of the project.”

Although I did not examine cards’ use in later iterations, drawing on the user study data and my personal experience of design process, I conjecture that cards’ use and value might evolve through design iterations. In early iterations, designers would use more cards in a relatively cursory way to frame and refine their design space, with much grouping and sorting of the cards. As the design ideas got more concrete and specific, fewer cards would be involved and more in-depth use may occur. Designers might want to check the picture (prototype) examples to get a better handle on the design concept and its implication.

5.3. RQ 1.c: How do the specific design features of Tango Cards support or limit such uses?

I used thematic analysis to find out what card design features worked and what did not work well in supporting different card uses. I look at card design features from two non-exclusive dimensions. The first higher-level dimension is the content, presentation, and form of the cards. A second lower-level dimension is different card elements; that is, title, design consideration, why, text example, and picture examples (see 3.4 the design details of Tango Cards). In this section, first I discuss the card
features that I believe supported card uses. Then I examine the card features that I suspect may limit card uses and values. Data collected from post-questionnaire provide supplementary support.

5.3.1. **How do card design features support card uses?**

I suggest that the following card features supported card uses.

- Clear information hierarchy (new)
- Short, punchy titles (new)
- Informative design considerations in inquisitive form (Hornecker, 2010)
- Physicality and mobility of the card form (Bekker & Antle, 2011; Hornecker, 2010; Lucero & Arrasvuori, 2010)

As indicated above, the first two features are new to Tango Cards and/or were not explicitly identified by previous card works. The latter two features have been used and reported on by previous card research. Next I will describe each card feature and provide examples as support.

**Clear Information Hierarchy**

I received very positive feedback about the information hierarchy design of Tango Cards. P24 said: "like the hierarchy...the title is big...I recognize it the best...’Consider’, ‘Why’, and ‘Example’ are ordered the way I want them to be." P19 similarly remarked: "I think it is the right order. I would read in this order..."

The information hierarchy let participants skim and scan the information as they liked and needed, supporting participants with varying levels of domain knowledge and familiarity with the concepts. Expert group participant P23 stated: “I didn't read any example text, ever. I really like the title, “Consider” and even the “Why” field... I didn't need to go that far to have an idea about how to change the design we had...” He later corrected himself and commented that for some cards that he did not have a clear idea about, he would use the examples. Another expert group participant P11, a senior game researcher, said that he only needed the title.
In the post-questionnaire, participants were asked to rate how they liked different elements of the cards on a 5-point Likert scale, with 5 being liked most. The mean rating and standard deviation for each element by both expert group and novice group is shown in Figure 5.5. Due to the small sample size and uneven group size, I were unable to run inferential statistics to see whether the difference was statistically significant. However, simple comparison of the values in the chart shows that the expert group participants preferred the title and design consideration ("Consider") to the other elements, while the novice group participants rated rationale ("Why") slightly above other elements. The mean ratings of other elements were quite close. One interpretation of this difference between the two groups is that the information provided by the title and design consideration was sufficient for expert group participants with a relatively good understanding of the domain knowledge to understand and apply the concept. The novice group participants with less domain knowledge needed access to more information on the cards to aid their understanding. Quotations from P23, P24, and P11 that I mentioned earlier in this section are in line with this interpretation. These findings suggest that the information architecture design supported designers of varying levels of familiarity with the domain knowledge and with different concepts on the cards.
Short, Punchy Titles

Using short, punchy phrases as titles, reinforced with large font size and colour, enabled the use of titles as a quick visual reference and communication shorthand during discussions. According to my observation and interview data, the title was the most heavily used card element. P19 commented that the titles “are well chosen” (interview question 2). In the post-questionnaire, participants were asked to rate how they liked different sections of the cards on a 5-point Likert scale (Q2), with 5 being liked most. Title was one of the two highest rated card elements by participants (the other element was design guidelines) with an average rating of 4.0 and standard deviation of 1.1.

Design Considerations as Questions

Participants overall had a very positive take on the design consideration element. As I reported in 5.3.1, design considerations and titles were rated highest (with a mean score 4.0). The standard deviation for the design considerations is 0.8. P19 said: “Sometimes the discussion gets muddy, but these (cards) keep things nice and distinct...clear questions you can answer...so good for reflection.” (Interview Q1) P24 stated: “Even if I have some background knowledge, it is nice to read one nicely formed sentence that refreshes your memory...maybe you don't know as well as you thought...” (Interview Q1)

Card Form

The handy card form, in addition to enabling basic grouping, sorting, and pointing that were prevalent among all the sessions, also enabled more advanced manipulation of the cards in two pairs as described in 5.1.3. Participants’ thoughts on the card form were positive. They liked that they could glance at, grab, group into piles, move cards around, and quickly refer to them. P12 said: “…like be able to visually glance and move them about … because that is the way my mind works.” His partner P11 also remarked: “I did enjoy the experience of talking about the concepts and pushing things together.” They said that the cards were “really good articles for guiding discussion” (P9) and provided “concrete reference to abstract ideas” (P11). P23 also found the mobility of the card form especially useful when they switched between the table and whiteboard during
their ideation. They were able to take some cards from the table and put them on the sill of whiteboard (see Figure 5.1). P23 commented that in one case they even appropriate cards to represent an element (little fish) in one of the models they came out with.

The only negative response about the card physical form was from P7 and P8 of session 4. They said that they did not see the value of the card form. P8 remarked: “…the form is a bit difficult to use…you have to spread it out, find the one, and read the one…not searchable.” They suggested having fixed position for each card. The notion of cards as being not searchable will be returned to in 5.3.2.

Participants also made some suggestions on how to further improve the card form, which I will discuss in 5.3.3.

5.3.2. How do card design features limit card uses?

The study data suggest the following card features may have limited card uses.

- Some picture (prototype) examples are not easy to understand and quick to use.
- The cards have “too much” information.
- Cards lack distinguishing visual features to make them searchable enough.

Complex Prototype (Picture) Examples

Picture examples on the back side were much less used than the text side. Many participants responded with negative feedback on the picture examples or simply did not use them. Several participants said some pictures examples of tangible learning systems (games) were difficult to understand. For example, P18 said that he found the cards using the Bifocal Models “intimidating”. P11 said prototypes from the university’s research projects (such as Kurio) were not accessible to general users outside the school.

Several other participants did not find the prototype examples helpful for ideation. For example, P23 commented (interview Q1):

"...the front side has more meaning to me. The back example is fine... but if I am going to glance over a great [sic] of cards, I don't think the
example will jump at me... as ideas are not so relevant to my design as the front was... (the text side) easier to translate... just easier for me to have the word "Identity" (referring to the 'Identity' card) and then go "does that fit into my design?"

P7 said he preferred reading text than seeing pictures to get the idea. Considering that designers are usually very visual people and pictures should be generally more provocative than text, P7's comment may actually indicate that the prototype examples were not inspiring and quick to understand.

P7 was one of the few participants who found the prototype examples helpful. He said the prototype examples are a good learning tool (interview Q1). When I asked him then why he still used the text side more, P7 responded:

"I have to read the front the understand the concept first, but I don't remember a single [sic] of them... the examples on the back helped me remember these concepts...the first thing to do is to read the cards over...read them all but didn't remember a single one of them... but I remember the (picture) examples..."

This suggests picture examples may work well as a visual reminder/identifier of cards.

In contrast, picture examples with more universal meanings generally received positive feedback, such as from well-known commercial games (Super Mario Bros.), everyday life (game controller), or diagrams. The cards of Intrinsic Rewards, Coherent Mapping, and Feedback as Scaffold, which used such picture examples, were identified by many participants as their favourite cards (interview Q4).

This finding indicates that participants perceived pictures more as something to be taken at face value and used quickly, rather than a visual pointer to further information that required additional reading to understand. When they failed to get the idea of the pictures examples quickly, they felt unsatisfied. The prototype examples did not meet their expectation as an ideation tool and for quick use. On the other hand, I would argue that the unfavourable feedback could also be attributed to a mismatch between the designated use of the picture examples as pointers to specific examples for further study, and the short duration of the design activities in which the cards were evaluated. The primary value of the prototype pictures for further research still needs to
be investigated. P9, P20, and P23 expressed that they would want to learn more about those picture examples if they had more time and during later iterations with their design ideas. P23 remarked:

“...examples would be more valuable if I have these - something I use all the time...then I can take some time read the detailed text and know the concept (of identity) better; then when I go to another design exercise after I got what this meant, it would have more meaning to me than if I just look at the title...”

In addition, the way the cards were set up might have affected participants’ use of picture examples on the back. For most sessions, I set out the cards with the text (front) side up because the front side was designed to provide key concept information. P24 stated that he did not use the picture examples because they were on the other side, making them less convenient to use. He said: “…tried to used the back a couple of times, but gave up…because they are on the back, I was not able to scan…there are 20 cards here...”

“Too Much” Information on the Cards

Three pairs of participants (session 4, 6, and 7) commented the cards were “a bit wordy” and/or there was too much information on the card. P11 said: “…diving into information-gathering mode of each card strongly kicked me out of the brainstorming in my domain area”. He suggested the information should “go minimum”, with only a phrase such as the title. P13 also commented: “It seems it is easier to get the message from just looking at the title and then looking at the picture … I can almost not read the writing …”

Such comments made sense when participants already knew the concepts well, such as the game cards for participants with game design experience. Yet they were confusing when participants knew little about the concepts, as was the case for novice group participants with the cards about tangibles. Further investigation revealed that contrary to my assumption, unfamiliarity with the tangible concepts made novice group participants of session 4 and 7 use the cards less or even ignore them, rather than read “abundant information” to pick up the concepts. For example, P8 of session 4 admitted that he used the tangible cards less than game cards. P8 said he found tangible cards
not that helpful because he was not familiar with them. He remarked: “[saw] TUI cards like introduction to these ideas; while seeing game cards like reminder to these ideas…”

Expert group participants P11 and P12 of session 6 (two PhD students with game research background) did examine the tangible cards that they knew less more closely (as I hoped). P12 said: “…never dealt with tangible cards, have to read them more carefully… because not that familiar with the concepts…” Despite this, P11 and P12 still disliked that reading information got in the way of their ideation (as P11 stated above). From these data, I see a clash between these participants’ preference for not being distracted from fast-paced ideation on one hand, and their need for the information on the cards on the other. P11 insightfully commented: “…the card is just this big. You can only do so much about them…constrained by space strongly. If your impulse is to put as much as possible on them, then you are going in the wrong direction…”

Lacking in Distinct Visual Elements for Search

I observed in many sessions instances where participants tried to retrieve a card they had discussed before from a pile of cards, but did not succeed. P11 criticized: “(The cards) didn’t support me to differentiate the concepts and remember them… if I have two cards side by side, I would have to sit there and read them a bunch of times.”

Lacking in Instructions

Two pairs of novice group participants commented that there were so many cards that they felt at a loss about how to deal with them. They said some instructions would be helpful. This indicates a need to include some suggested ways to use cards to help card users orient themselves when getting started, especially those less familiar with the domain knowledge. In addition, as reported in 5.1.3, in only two sessions, participants exhibited more advanced manipulation of the cards (e.g., arranging cards to externalize their analysis of old design and their design rationale). P17 revealed in the pre-questionnaire that she used IDEO Cards. P11 said he was an active poker player when I asked for his experience with general cards. Based on this, I suggest that soft rules and tips on possible ways of using the cards to support design may also help designers better leverage both the card content and form.
5.3.3. Suggestions for Improvement

Participants were requested and/or volunteered to give suggestions for improvements (for example, as a follow-up question for interview question 3). A summary of their suggestions is presented below.

Make Cards Quicker to Use for Ideation and/or More Searchable

Participants suggested using iconic representation (e.g., thumbnails of prototype pictures) to help differentiate cards (P11, P23). They also suggested putting minimum information (e.g., only title and guideline) and a general, easy-to-understand picture on the front side, and providing in-depth explanation and further reference on the back side (P7, P10). They thought this design could support both fast use like ideation and in-depth use like learning and research. P17 and P18 also suggested enhancing the use of the color coding (e.g., further categorize the cards by design activity/phase in which they are suggested to use, and color-code these categories).

Physical Form

Participants suggested making nicely round corners (P9, P23), using more sturdy material so that the cards can stand coffee spill “in a vigorous design environment” (P9), making the cards thicker and thus to pick up (P23).

I consider these suggestions reasonable for the problems identified in the user study. On the other hand, these suggestions were from only a few participants and have not been empirically examined. They provide inspirations for next round of design exploration.
5.4. RQ 2: Are cards an effective design tool to make design knowledge about tangible learning games accessible to designers throughout their design process?

5.4.1. Making Knowledge Accessible: How

I examine the accessibility of the cards from the following facets: Did designers find the knowledge easy to understand? Did designers find the knowledge useful and usable? How well did the cards fit into the design process? I analyze how the content, presentation, and form of the cards make cards accessible (Bekker & Antle, 2011), in terms of both individual use and group use.

A Quick Reminder

The knowledge presented in a short and concise format by cards provides designers with a quick reminder to the related knowledge and experience on their mind, which in turn elicits idea generation and refinement. As P12 neatly stated, the cards provided “a prod to memory”. Many participants mentioned “reminder” when they commented on cards’ value (session 4, 6, 10, 11). P24 stated: “…even if I have some background knowledge, it is nice to read one nicely formed sentence that refreshes your memory…maybe you don’t know as well as you thought… I found it really useful, even if it is a concept I heard before…” In a similar vein, P23 said: “…a sweet summary of research… things you’ve probably read somewhere but you didn’t remember in the moment… accelerate refining…”

A Learning-in-Use Tool

As I described in 5.2.4, participants had conflicting views on the value of the cards in supporting learning, especially learning in design. Opponent P11 thought the cards could not be a good ideation tool and a good learning tool at the same time because these two roles had conflicting requirements regarding the amount of information to include. As mentioned in 5.3.3, leveraging the two sides of the cards—using one side to support quick use like ideation and using the other side to support in-depth use such as learning might enable the cards to achieve both.
Common Language

As I described in 5.1.6, the concise information on the cards (especially the titles) serves as a common language and communication shorthand. This helps participants articulate their ideas and concerns and reach shared understanding during design discussions. This finding resonates with the findings of (Halskov & Dalsgård, 2006; Lucero & Arrasvuori, 2010).

Physical Anchor, Making Ideas Tangible

As I reported in 5.1.3 and 5.3.1, by supporting participants to perform a variety of physical actions such as pointing to, moving, grouping, and sorting on cards while thinking about their ideas, cards foster “thinking with hands”. Cards provide a physical anchor for abstract design knowledge during design discussion and support participants to externalize design rationale and analysis, thus making knowledge and ideas more concrete and accessible to themselves and to their partners. This finding aligns with and extends the findings of (Bekker & Antle, 2011; Hornecker, 2010; Lucero & Arrasvuori, 2010).

5.4.2. Making Knowledge Accessible: Who

As described in 5.3.1, the information hierarchy design of Tango Cards enabled participants to skim and scan different card elements as they needed. Expert and novice group participants showed different uses and preferences of different card elements. In this way, cards make the design knowledge accessible to users with varied knowledge levels with the design domain and varied familiarity with different cards/concepts.

However, the finding that some novice group participants used less or ignored Tangible Cards suggests that a certain level of prior knowledge about tangible learning games is necessary for designers to use the cards effectively and appreciate their value. This is also supported by survey data. In the post-questionnaire, participants were asked to rate the overall usefulness of the cards on a 5-point scale, with 5 as most useful. The average rating by expert group participants was 4.4 (standard deviation 0.5), while the average rating by novice group participants was 3.4 (standard deviation 0.9). So less familiarity with the design space made novice group participants value the cards less.
5.5. Summary of Findings

From Tango Cards study, I found that Tango Cards enabled a variety of uses that made design knowledge about tangible learning games accessible to designers. In particular, participants used cards to formatively evaluate design ideas to guide design discussion. The information hierarchy design was effective in supporting participants to use the cards quickly. It also supported users of varying knowledge levels with the design domain. The card titles provided a shared vocabulary and communication shorthand. The physical card form made design concepts more tangible and accessible to individual designers individually and as a group. Designers did not like those card features that slowed down card use and thus disturbed their work flow, such as dense prototype examples and “too much” information on the cards.

In the next chapter, I discuss the implications of the results and draw upon design considerations.
6. Discussion

In this chapter I begin with an overview and comparison of existing design cards (including Tango Cards) that aim to bring scholarly design knowledge to practice. I summarize the values of cards and synthesize knowledge about how to design cards from the findings of previous card research. From there, I extracted and abstracted design considerations for designing card-based design tools that make academic design knowledge accessible to designers during their design process. These design considerations can be generalized to design tools (card-based or alike) as knowledge transfer vehicles for other design spaces. This would especially be the case for design spaces where dense design knowledge exists. Finally I briefly discuss the limitation of Tango Cards study.

6.1. Design Cards: Overview and Comparison

Here I recap previous card works that I have reviewed in 2.5, with respect to their general design goal, the design activities that they focus on, the source knowledge that they transfer, and whether they have an associated technique. I also compare Tango Cards with previous cards from these aspects. Table 6.1 shows an overview and comparison of these design cards.

In terms of the design goal, Tango Cards is similar to DSD Cards (Bekker & Antle, 2011) in that it aims to both inform and inspire designers, while focusing on informing. In terms of the knowledge it communicates, it shares with Tangible Interaction Cards (Hornecker, 2010) and PLEX Cards (Lucero & Arrasvuori, 2010) in that it carries design guidelines that were transferred from conceptual design frameworks (with a few design guidelines that were not part of a framework). Tango Cards do not have rules associated with it.
### Table 6.1. An Overview and Comparison of Design Cards

<table>
<thead>
<tr>
<th>Common Goal</th>
<th>DSD Cards</th>
<th>Tangible Interaction Cards</th>
<th>PLEX Cards</th>
<th>Inspiration Cards</th>
<th>Tango Cards</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bringing design and/or domain knowledge to designers in their design practice</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design Activities that Focused on</td>
<td>Different design activities throughout design process</td>
<td>Early ideation</td>
<td>Early ideation</td>
<td>Early Ideation</td>
<td>Different design activities throughout design process</td>
</tr>
<tr>
<td>Source Knowledge (design knowledge and/or domain knowledge)</td>
<td>Domain knowledge (children’s developing cognitive, physical, social and emotional abilities)</td>
<td>Design knowledge (Tangible Interaction Framework)</td>
<td>Design knowledge (Playful Experiences framework)</td>
<td>Design and domain knowledge (knowledge about existing technology and application as well as about the specific project)</td>
<td>Design knowledge (Tangible Learning Design Framework and design principles about learning games)</td>
</tr>
<tr>
<td>Associated Methods?</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>

### 6.2. Value of Cards in Design Process

As I summarized in 2.5, previous card works have identified the following values of design cards in design process. These values were found again in Tango Cards study.

- Cards can stimulate the refinement and iteration of ideas (Bekker & Antle, 2011; Lucero & Arrasvuori, 2010).
- Cards can serve as ideation jump-off point (Halskov & Dalsgård, 2006; Hornecker, 2010).
- Card content provides designers with “repositories for statements and arguments” (Halskov & Dalsgård, 2006; Lucero & Arrasvuori, 2010).
- Cards can help plan and guide evaluation (Hornecker, 2010; Lucero & Arrasvuori, 2010).

In addition, a new value of design cards was identified in the Tango Cards study. Tango Cards were found to support designers to formatively evaluate their ideas.
Designers went back to cards from time to time during ideation to “ground their floating ideas” (as P24 phrased it). By using the cards, participants confirmed some ideas, corrected some other ideas, and realized some important aspects that were missing from their design.

The card form plays an important role. It has been found to support design process in the following ways:

- The small physical form of cards can afford physical manipulation (Hornecker, 2010).
- Cards can serve as an “orienting device” during design discussion to help team members reach shared understanding (Bekker & Antle, 2011; Hornecker, 2010).
- Cards can bookmark discussion ideas (Hornecker, 2010; Lucero & Arrasvuori, 2010).
- In Tango Cards study, two pairs went further and externalized their design rationale or analysis of old design ideas through more complex arrangement of cards.

6.3. Design Knowledge about Design Cards

The following pieces of design knowledge mentioned in previous card studies were corroborated by Tango Cards results. The evidence from the Tango Cards study that supported these guidelines has made them more potent.

Phrasing design guidelines as questions helps trigger ideation and reflection. Hornecker (2010) reported that participants found design guidelines phrased as questions inspiring. Hornecker encouraged participants to interpret the questions freely as she believed this conforms to the nature of creativity. Although Tango Cards aimed primarily for communicating the design guidelines as accurately as possible and actually discouraged free interpretation, the design considerations put in a question also received positive response from participants, as reported in 5.3.1.

Including in cards links to detailed, in-depth information about the concept may be a useful feature. Bekker and Antle (2011) proposed providing links to more detailed information about the original sources to prevent possible misinterpretation of
concepts, which could be caused by simplification and condensation as the source concepts were transferred to cards. Halskov and Dalsgård (2006) included reference to detailed information about the technology described on the Technology Cards of their Inspiration Cards. They did not report how participants used the reference and their feedback on it though. In my Tango Cards study, I did not have any specific activity to evaluate the prototype examples. Still, as described in 5.3.3, participants suggested providing in-depth explanation and further reference on the back side to complement the concise key information on the front side (P7, P10). I would also argue providing links to further, detailed information should be even more important and helpful for complex design spaces such as tangible learning games.

Using sturdy, thick material for cards could make the cards easier to use and more durable. Participants of DSD Cards study suggested using more sturdy materials for cards (Bekker & Antle, 2011). Likewise, as described in 5.3.3, participants of Tango Cards study suggested making the cards thicker so that they could be picked up more easily (P23) and using more sturdy material to enable the cards to endure vigorous design discussion (P9).

Providing instructions about how to use the cards to support design might help. All except the DSD Cards discussed in this chapter with the primary goal of providing inspiration have associated methods such as games, rules, or structure, varying in degrees of formalities to stimulate participation and innovation (Halskov & Dalsgård, 2006; Hornecker, 2010; Lucero & Arrasvuori, 2010). Previous studies found that such methods could foster discussions and make designers consider those aspects that did not seem immediately relevant (Hornecker, 2010). They suggested that the rules should not be too strict; otherwise they could block the thinking process rather than stimulating it (Hornecker, 2010; Lucero & Arrasvuori, 2010). The finding from Tango Card study as mentioned in 5.3.2 also indicates the necessity of providing some instructions.

6.3.1. Choosing Pictures for Design Cards

As explained in section 3.7, the pictures of most previous cards put emphasis on providing inspirations, which was consistent with their overall primary goal of inspiring
designers. They suggested that picture examples should be quick and easy to relate to (Hornecker, 2010; Lucero & Arrasvuori, 2010). They also argued that the pictures should not be too general or too specific (Halskov & Dalsgård, 2006; Hornecker, 2010; Lucero & Arrasvuori, 2010).

In Tango Cards study, I explored using pictures as pointers to further information. This aligns with the first priority of Tango Cards of informing designers. I used pictures of tangible learning games for most cards. As reported in Chapter 5, the user study findings suggested that my image choices were not successful, at least for initial ideation that I directly evaluated. Participants found many prototype examples being too unfamiliar and complex to access. They preferred those few picture examples that have more universal meanings, such as pictures of commercial games and human activities. They also did not want to flip the cards during design discussion because it interrupted the flow. Although I did not evaluate the prototype examples in their designated activities, this result suggests that designers may expect pictures to stand on their own and to be used at their face value, rather than as pointers to in-depth information. Finding or designing pictures that meet such criteria is especially challenging if at all possible for complex design spaces such as tangible learning games. I conjecture that everyday pictures might be a direction to go. They may not able to fully communicate the complex concepts, but they at least provide quick access and serve as an effective visual reminder.

6.4. Design Considerations

An analysis and synthesis of Tango Cards study findings shows that supporting rather than distract from design flow is important for the effectiveness of design cards. All the card design features that I found work well contributed to making the cards quick to use and/or fit into the design flow. For example, the information architecture design supported scanning and skimming card information. As another example, the card titles, serving as a common vocabulary and communication shorthand, helped accelerate reaching a shared understanding. On the other hand, card design features that were found unfavourable hindered the design flow in some way; for example, “too much
information” could defeat its purpose. This echoes with Rogers’ (2004) claim that for theory to best inform design, the ways of knowledge transfer should focus on the design process and support the ways that designer work.

Based on my study findings and experiences, I suggest several considerations for the creation of design cards, with the dual goal of informing designers and supporting their design flow (Deng, Antle & Neustaedter, 2014).

**Include “appropriate” amount of information.** As I observed in the study, there existed a tension between participants’ preference for staying focused on the fast-paced ideation on one hand, and their need for card information on the other. To mitigate the tension, I argue that a delicate balance should be achieved between providing adequate information to effectively communicate the design knowledge and minimize the cards’ distraction of designer’s attention from design flow, with the priority given to the latter. After all, card content was “secondary to [their] thinking” (P13). I suggest considering these factors when deciding the amount of information to present on the cards: the knowledge level of target users of the design domain; the design activities that the cards focus on (e.g., ideation, evaluation, learning and research); and the work style and preference of target users.

Transforming scholarly design knowledge into a set of cards is a process of extraction and simplification. As a result, much context and nuances of the original knowledge is lost inevitably during this process. This entails a risk of misinterpretation (Bekker & Antle, 2011; Hornecker, 2010). Inspired by (Bekker & Antle, 2011), I suggest providing links to detailed information (e.g., through a QR code) from the source literature to rectify this.

**Implement effective information architecture** to support skimming and scanning the information on the cards and users of different knowledge levels. In Tango Cards, the five elements are spatially arranged by their importance, from “must read” (on the front, top) to “read if necessary” (on the back, bottom). Visual characteristics are also applied to reinforce the information architecture; for example, different font sizes are used to signal the relative importance of the elements. The section headings (title,
“Consider”, “Why”, and “Example”) are highlighted using the colour of the card category (tangible and game). These features were found to work well in my study.

**Apply visual design to make cards highly searchable;** that is, make it easy to differentiate individual cards from each other. Previous card research has mentioned this briefly but did not delve into specifics. For example, it was suggested colour coding could make cards more searchable (Bekker & Antle, 2011; Hornecker, 2010). Tango Cards were colour coded by the two categories (tangible and game). In addition, the titles in a large font stood out and worked effectively as a visual identifier for the cards. Participants also suggested that further colour coding (e.g., mapping colors to design activities in which the cards are recommended to use), or using icons or thumbnails of picture examples would make the cards even more searchable. I could also consider introducing accessories such as clothes pegs for designers to mark cards that they consider important.

### 6.5. Limitations

#### 6.5.1. Limitations of Expert Review

The expert review was not anonymous. Expert reviewers were my supervisor Dr. Antle's and/or my colleagues and professional connections. This relationship might have introduced bias. Still, as reported in 3.8.2, expert reviews did provide feedback on what they did not like about the cards and their suggestions for improvements.

#### 6.5.2. Limitations of User Study

As previously discussed in chapter 5, due to the time and scope constraints of a masters’ thesis, I only evaluated Tango Cards in two design activities (initial concept development and redesign). Both activities were conducted within a time frame of 45 minutes, during which most participants just had time to finish their first iteration. I did not get chance to evaluate the cards in more design activities (such as in dedicated, summative evaluation sessions, in learning and research activities). I only inferred the
value of the cards in other design activities from some card uses that participants demonstrated in the two design activities.

Another limitation is that participants were still in the process of learning the concepts on the cards as well as how to use the cards due to the short duration of the study. They might use the cards differently when they get more familiar with the cards. For example, P23 commented that he and his partner used the cards more in the second design activity. Both P20 and P23 remarked that the cards would be more useful if they had them for longer time and read more of it. This feedback suggests that participants may still be in the learning phase during the design activities.

Also, about half of the pairs who participated in the Tango Cards study were “novices” who lacked TUI knowledge, although I would argue this may not be a limitation because in real projects it is not rare that designers do not know everything of the design space when they start the project, especially for a complex design space like tangible learning games. It is actually interesting and valuable to observe how designers pick up the knowledge from and beyond the cards during their design process.

Last, Tango Cards were examined in lab settings with student designers/researchers. The way they used the cards might be different from professional designers who work on real projects.
7. Conclusion

7.1. Recap of Research and Findings

In this thesis, I designed Tango Cards, a card-based design tool to address the need for a design tool to make the emerging body of academic design knowledge about tangible learning games accessible to designers. Based on the design goal of Tango Cards and previous card works, I translated a selection of design knowledge that was produced through academic design-based research into a card set. I conducted expert reviews, and then revised the cards. I conducted a user study with 12 pairs of design students to investigate how designers used the cards, how card characteristics supported or limited card use, and to better understand in what situations and for whom the cards were effective.

From Tango Cards study, I found that Tango Cards enabled a variety of uses that made design knowledge about tangible learning games accessible to designers. In particular, participants used cards to formatively evaluate design ideas to guide their design discussion. The information hierarchy design was found effective in supporting participants to use the cards quickly. It was also found effective in supporting users of varying knowledge levels with the design domain. The card titles provided a shared vocabulary and communication shorthand. The physical card form made the design ideas more tangible and accessible to individual designers and to designers as a group. Designers did not like those card features that slowed down the card use and disturbed their work flow, such as complex prototype examples and “too much” information on the cards. Drawing on the findings of Tango Cards, I set forth design considerations that can help others create design tools (card-based or alike) that make academic design knowledge of other design spaces accessible to designers.
7.2. Contribution

The contribution of Tango Cards is at three levels. At a base level, Tango Cards as an artefact, contribute a preliminary design tool to bridge the gap between the theory and practice for the design space of tangible learning games. At an intermediate level, my card study is the first card study that consciously explored designing cards with informing (not inspiring) as the primary focus. At a more general level, my work is an initial effort to examine, synthesize, and abstract existing design knowledge (from previous cards and Tango Cards) about how to create design cards to bring scholarly design knowledge to practice. My work has made this body of knowledge more tangible and generalizable.

7.3. Future Research

As future work, I would like to revise the cards based on the findings and feedback from the user study. Then I want to evaluate the updated cards in industry-based projects, which have longer timespans and real-life constraints. Such settings will enable me to examine the utility of cards in other design activities (e.g. summative evaluation, later-stage iterations, and for designated learning and research), and observe how designers adapt card use over time as they become more familiar with the cards.
References


Mazalek, A., & van den Hoven, E. (2009). Framing tangible interaction frameworks. AI EDAM, 23(Special Issue 03), 225–235. doi:10.1017/S0890060409000201


Appendix A.

A Complete List of Tango Cards (Title and Design Guideline)

<table>
<thead>
<tr>
<th>Tangible Cards</th>
<th>Game Cards</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiple Modalities</td>
<td>Best Fit Media</td>
</tr>
<tr>
<td>Multiple Representations</td>
<td>Integrating Content and Play</td>
</tr>
<tr>
<td>Coherent Mapping</td>
<td>Feedback as Scaffold</td>
</tr>
<tr>
<td>Pause for Reflection</td>
<td>Identity</td>
</tr>
<tr>
<td>Thinking with Hands</td>
<td>Smart Tools</td>
</tr>
<tr>
<td>Simple Input Actions</td>
<td>Well-Ordered Problems</td>
</tr>
<tr>
<td>Linking through Metaphors</td>
<td>Simplified Systems</td>
</tr>
<tr>
<td>Dynamic Exploration</td>
<td>Low-Risk Exploration</td>
</tr>
<tr>
<td>Shared Understanding</td>
<td>Pleasantly Frustrating</td>
</tr>
<tr>
<td>Working Together</td>
<td>Cycles of Practice and Challenges</td>
</tr>
<tr>
<td>Co-dependent Access Point</td>
<td>Information &quot;On Demand&quot; and &quot;Just in time&quot;</td>
</tr>
<tr>
<td></td>
<td>Relating Skills to Goals</td>
</tr>
<tr>
<td></td>
<td>Multiple Pathways</td>
</tr>
<tr>
<td></td>
<td>Intrinsic Rewards</td>
</tr>
</tbody>
</table>
Appendix B.


<table>
<thead>
<tr>
<th>Guidelines</th>
<th>Physical Objects</th>
<th>Digital Objects</th>
<th>Actions on Objects</th>
<th>Informational Relations</th>
<th>Learning Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Distributing information across modalities can increase effective</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>working memory capacity.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Integrating spatial sources of information across and within modalities</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>within modalities can minimize the extraneous cognitive load</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>imposed to synthesize inputs.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Using concrete representations can support interpretation of</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>symbolic representations of abstract concepts.</td>
<td></td>
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</tr>
<tr>
<td>4. Making mappings between the form and behavior of physical and/or</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>digital objects and real-world entities coherent can reduce extraneous</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>cognitive load.</td>
<td></td>
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</tr>
<tr>
<td>5. Creating contextualized tasks or personal objects can support</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>learners in forming individually meaningful goals for interacting with</td>
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<tr>
<td>the TUI.</td>
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<tr>
<td>6. Using spatial, physical, temporal or relational properties can slow</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>down interaction and trigger reflection.</td>
<td></td>
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<td>7. Distributing parts of mental operations to actions on physical and/or</td>
<td></td>
<td></td>
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<td>X</td>
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<tr>
<td>digital objects can simplify and support mental skills.</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
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<tr>
<td>8. Leveraging image schemas in input actions can improve usability and</td>
<td></td>
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<tr>
<td>system learnability.</td>
<td></td>
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<tr>
<td>9. Using conceptual metaphor(s) based on image schemas to structure</td>
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<tr>
<td>interaction mappings may bootstrap learning of abstract concepts.</td>
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<td></td>
<td>X</td>
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<tr>
<td>10. Designing objects that allow for spatial re-configuration can enable</td>
<td>X</td>
<td>X</td>
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<tr>
<td>mutual adaptation of ideas.</td>
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<td>11. Creating configurations in which participants can monitor each</td>
<td>X</td>
<td>X</td>
<td></td>
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<tr>
<td>other’s activity and gaze can support the development of shared</td>
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<tr>
<td>understandings.</td>
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<tr>
<td>12. Distributing roles, information and controls across the TUI learning</td>
<td>X</td>
<td></td>
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<td>X</td>
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<tr>
<td>environment can promote negotiation and collaboration.</td>
<td></td>
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<tr>
<td>13. Creating constrained or co-dependent access points schemes can</td>
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<tr>
<td>compel learners to negotiate with each other.</td>
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<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>
Appendix C.

Selected Learning Game Design Principles (Gee, 2007a; Fisch, 2005)

<table>
<thead>
<tr>
<th>Principle</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Customize</strong></td>
<td>Different styles of learning work better for different people. People cannot be agents of their own learning if they cannot make decisions about how their learning will work. At the same time, they should be able (and encouraged) to try new styles.</td>
</tr>
<tr>
<td><strong>Identity</strong></td>
<td>Deep learning requires an extended commitment and such a commitment is powerfully recruited when people take on a new identity they value and in which they become heavily invested – whether this be a child ‘being a scientist doing science’ in a classroom or an adult taking on a new role at work.</td>
</tr>
<tr>
<td><strong>Manipulation and Distributed Knowledge</strong></td>
<td>Cognitive research suggests that for humans perception and action are deeply interconnected (Barsalou, 1999a, b; Clark, 1997; Glenberg, 1997; Glenberg &amp; Robertson, 1999). Thus, fine-grained action at a distance – for example, when a person is manipulating a robot at a distance or watering a garden via a webcam on the Internet – causes humans to feel as if their bodies and minds have stretched into a new space (Clark, 2003). More generally, humans feel expanded and empowered when they can manipulate powerful tools in intricate ways that extend their area of effectiveness.</td>
</tr>
<tr>
<td><strong>Well-ordered Problems</strong></td>
<td>Given human creativity, if learners face problems early on that are too free-form or too complex, they often form creative hypotheses about how to solve these problems, but hypotheses that don't work well for later problems (even for simpler ones, let alone harder ones). They have been sent down a ‘garden path’. The problems learners face early on are crucial and should be well designed to lead them to hypotheses that work well, not just on these problems, but as aspects of the solutions of later, harder problems, as well.</td>
</tr>
<tr>
<td><strong>Pleasantly Frustrating</strong></td>
<td>Learning works best when new challenges are pleasantly frustrating in the sense of being felt by learners to be at the outer edge of, but within, their ‘regime of competence’. That is, these challenges feel hard, but ‘doable’. Furthermore, learners feel – and get evidence – that their effort is paying off in the sense that they can see, even when they fail, how and if they are making</td>
</tr>
</tbody>
</table>
Cycles of Expertise

Principle: Expertise is formed in any area by repeated cycles of learners practicing skills until they are nearly automatic, then having those skills fail in ways that cause the learners to have to think again and learn anew (Bereiter & Scardamalia, 1993). Then they practice this new skill set to an automatic level of mastery only to see it, too, eventually be challenged. In fact, this is the whole point of levels and bosses. Each level exposes the players to new challenges and allows them to get good at solving them. They are then confronted with a boss that makes them use these skills together with new ones they have to learn, and integrate with the old ones, to beat the boss. Then they move on to a new level and the process starts again.

Information ‘On Demand’ and ‘Just in Time’

Principle: Human beings are quite poor at using verbal information (i.e. words) when given lots of it out of context and before they can see how it applies in actual situations. They use verbal information best when it is given ‘just in time’ (when they can put it to use) and ‘on demand’ (when they feel they need it).

Fish Tanks

Principle: In the real world, a fish tank can be a little simplified ecosystem that clearly displays some critical variables and their interactions that are otherwise obscured in the highly complex ecosystem in the real world. Using the term metaphorically, fish tanks are good for learning: if we create simplified systems, stressing a few key variables and their interactions, learners who would otherwise be overwhelmed by a complex system (e.g. Newton’s Laws of Motion operating in the real world) get to see some basic relationships at work and take the first steps towards their eventual mastery of the real system (e.g. they begin to know what to pay attention to).

Sandboxes

Principle: Sandboxes in the real world are safe havens for children that still look and feel like the real world. Using the term metaphorically, sandboxes are good for learning: if learners are put into a situation that feels like the real thing, but with risks and dangers greatly mitigated, they can learn well and still feel a sense of authenticity and accomplishment.

Skills as Strategies

Principle: There is a paradox involving skills: People don’t like practicing skills out of context over and over again, since they find such skill practice meaningless, but, without lots of skill practice, they cannot really get any good at what they are trying to learn. People learn and practice skills best when they see a set of related skills as a strategy to accomplish goals they want to accomplish.
Match specific educational topics or concepts to their most appropriate medium.

Make educational content at the heart of game play, so that children engage in the targeted real-world behaviour or thinking as they play the game.

Design feedback and hint structures in ways that support and scaffold children into difficult content.
Appendix D.

Expert Review Protocol and Interview Questions

**Briefing [10 min]**

Introductions

Verbal consent
  
  Okay to record?
  
  Okay to use in current and future research?
  
  Privacy protected

Open the cards and interview protocol

Have read the cards, right? Need me to introduce the cards again?

**About Tango cards**

Tango cards are designed for designers of tangible learning games.

The goal of Tango cards is to make academic design knowledge about how to design effective tangible games for learning more accessible and usable to designers.

Tango cards consist of two categories: interaction and game (color coded). The interaction cards provide design considerations for tangible interactions for learning purpose, while the game cards provide design considerations for educational games. The learning aspect is embedded in both categories.

The design guidelines of Tango cards are distilled from existing research/literature on tangible interaction (based on the Tangible Learning Design Framework by Antle & Wise, 2012) and learning games (from researches of Gee, Fisch, Jenson, etc.). The illustrations for the cards are mostly from existing research prototypes for tangible learning games when they were available.

Each Tango card has two sides. The front side consists of a descriptive title, the design guideline, rationale for the design guideline, and a general example about design practices that reflect this design guideline. On the back side, there is the descriptive title, pictures that illustrate the design guideline, and a short description for the pictures.

**Review Goal**

To validate the design quality of Tango cards in terms of wording, presentation, and information accuracy

To get suggestions for improvements

To get input (e.g., how the cards can be used) to inspire/inform design-in-use study design

Any questions so far?
Interview questions:

**Content: [20 min]**
What was your overall impression of the cards?
Were there any cards that had wording that wasn’t easy to understand? If so, which cards and what was the wording?
Do you think that the information at a right level of detail, and/or achieves a good balance between concreteness and abstraction? If not, please specify. And maybe your suggested changes?
For each card, do you think that the title reflects the card content well? If not, what title would you use for this card?
Are there any cards that contain information that you think is inaccurate? If so, which ones?

**Pictures [10 min]**
For most cards, did you find that the pictures helped illustrate the guideline? If not, for which cards did you find it confusing/difficult to relate the picture and the guideline? Any suggestions for improvements?
For each card, do you think the short descriptions for the pictures easy to understand? Enhance interpretation? If not, your suggested changes?

**General card design [5 min]**
Do you have any comments on the visual design of the cards (card layout, etc.)?

**Overall comments: [10 min]**
Are there any topics that you think should be included (but are not)?
How might you use the cards (in different design activities and phases)?
What do you think is the best thing about the cards in terms of making information about tangible games for learning more accessible for designers?
What are your biggest concerns/doubts about the cards?
Appendix E.

User Study: Design Cases

Case 1: Redesigning and enhancing a learning goal of game Fizzy’s Balance Bots

Balance Bots game interface

Fizzy’s Balance Bots is a web-based interactive game for children aged 6-7 to learn the importance of healthy eating and practice algebra skills (especially division). In the game, children are asked to rebalance the robot’s diets by swapping the food between them. The robots are able to dance again when the nutritional elements (such as milk, fruit, grain, and protein) are evenly distributed amongst robots.

Design Task

Play Balance Bots (available at [http://pbskids.org/lunchlab/#/games/balance-bot](http://pbskids.org/lunchlab/#/games/balance-bot)) for a few rounds, and think about how well the game design serves its learning goals.

- Redesign the Balance Bots game to be a TUI game in which children will interact with the game using physical objects on a digital tabletop. You can decide what the physical objects should look like, what on-screen elements the game should contain, and how the physical and digital elements interact.
- Make the game better meet its goal of educating balanced meals and nutrition knowledge.

Explore how the information from different cards can inspire/inform your design.
Write down and sketch out your ideas, and give a 5-min presentation at the end of session. Address the following in your presentation (use your sketches and/or storyboard to help convey your ideas):

- Your TUI design
- The updated and/or new game mechanics and features
- Justify your design choices and explain where your ideas come from.

Case 2. Ideation for a tangible learning game to help children learn the concept of sustainable land use planning

Develop initial ideas for a tangible learning game that can help children understand the complexity of building a sustainable environment and different (and often conflicting) factors to consider. The game should allow multiple players. Players must work together to provide the best balance between supporting the needs of the community and maintaining a sustainable environment within the resource constraints.

Explore how information from different cards can inspire/inform your design.

**Sustainable land use planning – Background knowledge (to help you get started)**

When building a sustainable environment, you may want to consider the following goals and constraints. You may have to make trade-offs among the conflicting goals and among the interests of different stakeholders.

- Sustaining economic growth to support the development of the community.
- Producing enough energy to power the community. (You may also want to make the energy as affordable and environmentally friendly as possible.)
- Maintaining/improving environmental quality for sustainable development
- Investing in the research of new energy sources and technologies
- …

Write down and sketch out your ideas, and give a 5-min presentation at the end of the session. Address the following in your presentation (use your sketches and/or storyboard to help convey your ideas):

- The game mechanics and features, and how tangible interaction supports the game ideas.
- Justify your design ideas and explain where your arguments/ideas come from.
Appendix F.

User Study: Pre- and Post-Questionnaire, Post-Interview Questions

Tango Cards Study Pre-Questionnaire

Team# | Participant #

Please fill out this survey to the best of your ability. If you have any questions, please ask.

Age: _______  |  Gender:  Male  Female

What level of education are you pursuing? What year are you in?
BA/BSc, Year______  MA/MSc, Year______  PhD, Year______
Program/Major: _______________________________________
You are from: IAT431/IAT432  SFU Game Developers Club  Other______

Please briefly describe your interaction/interface design experience: How many projects have you been involved in as a main contributor? What interaction design related courses have you taken?

Please briefly describe your game design experience: How many projects have you been involved in as a main contributor? What game design related courses have you taken?

Have you used design cards (like IDEO Method Cards) in your interaction/interface design activities before? If so, please briefly describe the cards, the activities, and how you used the cards.

Have you used design cards in your game design activity before? If so, please briefly describe the cards, the activities, and how you used the cards.

Are you familiar with the concept of “tangible learning games”?  YES  NO
If yes, please briefly describe your experience with the concept.
Tango Cards Study Post-Survey

Team #  Participant #

Rate the following questions along a scale of 1-5 (least to most) or circle "No opinion," if you are unable to rate. If you have any questions, please ask.

1. How valuable do you think the cards are in serving the following purposes?

   Initial brainstorming?
   (Not very ) 1 2 3 4 5 (Very)  No opinion

   To inspire and inform concrete ideas?
   (Not very ) 1 2 3 4 5 (Very)  No opinion

   To redesign a game to meet new design goals?
   (Not very ) 1 2 3 4 5 (Very)  No opinion

   As an evaluation / post hoc analysis tool?
   (Not very ) 1 2 3 4 5 (Very)  No opinion

   As a learning tool?
   (Not very ) 1 2 3 4 5 (Very)  No opinion

2. How do you like each part of the cards?

   Title
   (Not very much) 1 2 3 4 5 (Very much)  No opinion

   Guideline (Consider)
   (Not very much) 1 2 3 4 5 (Very much)  No opinion

   Rationale (Why)
   (Not very much) 1 2 3 4 5 (Very much)  No opinion

   Example
   (Not very much) 1 2 3 4 5 (Very much)  No opinion

   Prototype example on the other side
   (Not very much) 1 2 3 4 5 (Very much)  No opinion

3. How do you like the visual design and presentation of the cards?
   (Not very much) 1 2 3 4 5 (Very much)  No opinion

4. Rate the overall usefulness of the cards.
   (Not very much) 1 2 3 4 5 (Very much)  No opinion
<table>
<thead>
<tr>
<th>Question</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. What was your overall impression of the cards?</td>
</tr>
<tr>
<td>2. How might you use these cards (in different phases/activities of a design project)?</td>
</tr>
<tr>
<td>3. What do you like and dislike the most about the cards?</td>
</tr>
<tr>
<td>4. Name the top three cards you like the most. Why?</td>
</tr>
<tr>
<td>5. Are there any cards/topics you would never use? Why?</td>
</tr>
<tr>
<td>6. Did you find any topics/information missing from the cards?</td>
</tr>
<tr>
<td>7. Any additional comments?</td>
</tr>
</tbody>
</table>
Appendix G.

User Study Protocol

Tango Cards Study Protocol
Total Time: approximately 150 minutes

1. Preparation (Give 45 min to set up!)
   0. The day before:
      a. Audio recorder: Charge the battery, and memory usage;
      b. Video recorder: Check battery life and tape usage;
      c. READY CASH - $10 AND $20
   1. Have package for each participant ready:
      • TWO copies of ethics form (Be sure to number the forms with the participant numbers & name)
      • 1 acknowledgment of receipt of compensation form
      • 1 pre-session questionnaires & pens (NO participant name; Team No. and Participant No. pre-filled)
      • 1 post-session questionnaires & pens (NO participant name; Team No. and Participant No. pre-filled)
   2. Ready THREE copies of the two design briefs
   3. Ready the data sheets, on clip board (Allen will use an electronic copy.)
   4. Ready TWO copies of study protocol.
   5. Ready the camera
   6. Ready the audio recorder
   7. Prepare video documentation
      • Two tapes (switch after one design activity)
      • LABEL the video tapes
      • Rewind the tapes to beginning; set to SP
      • Video recorder on a tripod, decide best position; - should opposite the participants; should shoot participants’ actions on cards, facial expressions,
      • Decide the seating of participants;
   8. Ready Tango Cards
   9. Ready the slides introducing tangible learning games
   10. Ready the QR linked video files and papers.
   11. Ready design materials (blank paper, index card, post-it, pencil, sharpie pens, eraser)
   12. iPhone – setting – no lock (so that I can use the stopwatch without interruption)
   13. Treats ready, cups, water
   14. Table layout – enough space for cards!

2. Meet participants: (10-15 minutes)
   1. Introduce the pair to each other, introduce the researchers
   2. Provide an overview of the session. STATE THAT THEY CAN STOP AT ANYTIME.
   3. Explain that we will be videotaping and recording.
   4. Provide ethics forms for signature (Be sure to witness the forms).
      Note: Ask them whether they want to keep a copy.
   5. Ask participants to fill out the pre-session questionnaires.
3. Introduction and tutorial (15 minutes) – Tango Cards and Tangible Learning Games
   1. Introduce Tangible Learning Games
      Note: Ask if they have any questions and need any clarification.
   2. Show example game videos
   3. Introduce Tango Cards and let participants explore the card deck (5 min).
      Note:
      Lay out the cards: text side up.
      Explain how the fake QR code works.

4. Design case 1 (45 minutes)
   1. Introduce the design activities (Be brief. Don’t describe the game in details.)

Video documentation: Turn on the video recorder

Synchronize watches
   2. Participants start working on the design case.
      • Remind them of using the cards!
      • Observe participants working on the design case using the cards.
      • Take notes and document in an unobtrusive manner as possible by video.
      • Take picture for “big moments”.

35 min – Remind participants they have 5 min left
40 min – Ask participants to start participation.
   3. Participants start presentation.
      • Take notes and take pictures of final design.

Video documentation: Turn off the video recorder

SWITCH to a NEW tape!

BREAK – 5 min
Let participants have a short break, go to the bathroom, take some snacks etc. as needed.

5. Design case 2 (45 minutes)

Video documentation: Turn on the video recorder

Synchronize watches
   1. Participants start working on the design case.
      • Observe participants working on the design case using the cards.
      • Take notes and document in an unobtrusive manner as possible by video.
      • Take picture for “big moments”.

35 min – Remind participants they have 5 min left
40 min – Ask participants to start participation.
   2. Participants start presentation.
      • Take notes and take pictures of final design.

Video documentation: Turn off the video recorder

6. Post-Session Questionnaire and Interviews (30 minutes)
   1. Distribute the questionnaires and be in the room to help them complete the questionnaires.

Audio Documentation: Turn on the voice recorder
   2. Conduct a group interview using the post-session semi-structured questions.

Audio Documentation: Turn off the voice recorder

7. End
   1. Give participants compensation
   2. Ask them to sign the acknowledgment of receipt of compensation form
   3. Thank them for participating!
Appendix H.

Ethics Approval

Hello Ying,

Your application has been categorized as ‘Minimal Risk’ and approved by the Director, Office of Research Ethics on behalf of the Research Ethics Board, in accordance with University Policy r20.01 (http://www.sfu.ca/policies/research/r20.01.htm).

The Research Ethics Board reviews and may amend decisions made independently by the Director, Chair or Deputy Chair at the regular monthly meeting of the Board.

Please acknowledge receipt of this Notification of Status by email to [youremail] and include the file number as shown above as the first item in the Subject Line.

You should get a letter shortly. Note: All letters are sent to the PI addressed to the Department, School or Faculty for Faculty and Graduate Students. Letters to Undergraduate Students are sent to their Faculty Supervisor.

Good luck with the project,

Hal Weinberg, Director