User Perceptions of Adaptivity in Ubiquitous Systems: A Critical Exploration

by

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Abstract

This dissertation addresses a gap in the field of designing adaptivity for ubiquitous systems by taking a critical look at the notion of "adaptivity" from the perspective of user experience. Through a set of detailed case studies of several different systems, I develop a set of concepts related to the experience of adaptivity. These concepts are supplemented by a set of design considerations that can assist in designers in thinking about key issues connected to the concepts. My work is a first take on untangling the complex relationship between ubiquity, adaptivity and the design of novel systems.

Through a collective case study, I examine the differences between the intended and actual experience of three adaptive systems: the Reading Glove, Kurio, and socio-ec(h)o. The Reading Glove was an interactive storytelling system involving a piece of wearable technology that allowed participants to trigger story information by picking up objects. An adaptive component guided the reader through the story by recommending objects to interact with next. Kurio was a museum guide system that involved playing an educational game distributed across a set of handheld and tabletop devices. The adaptive component attempted to gauge the appropriate learning level in assigning tasks to each individual. Socio-ec(h)o was a group game played in an ambient environment, where teams of players had to coordinate their physical movements to solve riddle-based levels. Characteristics of the group's movement, location and position were used to adapt the system's ambient feedback system.

From the analysis of these cases, I draw out a set of interrelated concepts that are useful for designing adaptive systems. The experience of adaptivity is impacted by the user's *awareness* of adaptivity and the *interpretation* of the adaptive effects. Factors like *trust, surprise, augmentation, legibility, collapse, confusion, control* and *choice* also play a role in grappling with intelligent components within complex systems. This research highlights the complexity involved in designing the adaptive components of computing systems making use of tangible and other novel interface styles by examining some of the experiential effects of these new interaction paradigms and how they relate to the intentions of the designers.

Keywords: adaptivity; ubiquitous computing; tangible computing; user experience; user modeling; artificial intelligence

Dedication

This dissertation is dedicated to my loved ones:

to Josh, who walks every road with me and without whom I would simply be lost,

to Dave & Laura, who trod the dark road of the dissertation before me and whose wisdom and encouragement lit my way,

and

to Mom & Dad, who always let me forge my own path even when they didn't understand it and whose pride and support I have never doubted.

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Table of Contents

Approval ii
Abstract iii
Dedication iv
Acknowledgements v
Table of Contents vi
List of Figures ix
List of Tables x

1: Introduction 1
1.1 Research Overview 2
1.1.1 Research Questions 3
1.1.2 Collective Case Study 3
1.2 Document Organization 4

2: Literature Review 5
2.1 Tangible and Ubiquitous Computing 5
2.1.1 Learning to Interact with Tangible and Ubiquitous Computing 7
2.1.2 Designing for Tangible and Ubiquitous Computing 9
2.2 Adaptivity and Intelligence 13
2.2.1 Developing Adaptive Systems 13
2.2.2 Tackling Artificial Intelligence 15
2.3 Designing User Experience 18
2.3.1 Related Work 19

3: Methodology 21
3.1 Case Study 21
3.1.1 Chosen Cases 22
3.2 Research Questions 24
3.2.1 Propositions 25
3.2.2 Units of analysis 25
3.2.3 Conceptual Framework 26
3.3 Data Collected 27
3.3.1 Semi-structured Interviews 27
3.3.2 Observation of System Interaction 27
3.3.3 Questionnaires 28
3.3.4 System logs 28
3.3.5 Design Documents 28

3.4 Analytical Strategy 28
3.5 Validity 30
3.5.1 Clarification of Bias 30
3.5.2 Rich, Thick Description 31
3.5.3 Triangulation 31

4: Case 1: The Reading Glove 33
4.1 The Reading Glove Description 33
4.1.1 Interaction and Story 33
4.1.2 Technical Details 34
4.2 The Reading Glove Study 34
4.2.1 Study Protocol 35
4.2.2 Data Collected 35
4.2.3 Units of Analysis 36
4.3 Adaptivity in the Reading Glove 37
4.3.1 Reading Glove Ontology 38
4.3.2 Reading Glove Recommendations 39
4.3.3 Reading Glove Recommender types 39
4.4 Reading Glove Analysis 42
4.4.1 Proposition 1: Intended Benefit vs Actual Experience 42
4.4.2 Proposition 2: Interaction with Tangibility & Ubiquity 57
4.4.3 Proposition 3: The Effect of Adaptivity 63
4.4.4 Reading Glove Discussion 70

5: Case 2: Kurio 75
5.1 Kurio Description 75
5.1.1 Interaction and Experience 75
5.1.2 Technical Details 77
5.2 Kurio Study 78
5.2.1 Study Protocol 79
5.2.2 Data Collected 79
5.2.3 Units of Analysis 80
5.3 Adaptivity in Kurio 81
5.3.1 Individual Models 81
5.3.2 Group Models 84
5.4 Kurio Analysis 85
5.4.1 Proposition 1: Intended Benefit vs Actual Experience 85
5.4.2 Proposition 2: Interaction with Tangibility & Ubiquity 89
5.4.3 Proposition 3: The Effect of Adaptivity 95
5.4.4 Kurio Discussion 97

6: Case 3: Socio-ec(h)o 101
6.1 Socio-ec(h)o Description 101
6.1.1 Interaction and Experience 101
6.1.2 Technical Details 103

6.2 Adaptivity in Socio-ec(h)o 105
6.3 Socio-ec(h)o Study 105
6.3.1 Study Protocol 105
6.3.2 Data Collected 106
6.3.3 Units of Analysis 107
6.4 Socio-ec(h)o Analysis 107
6.4.1 Proposition 1: Intended Benefit vs Actual Experience 107
6.4.2 Proposition 2: Interaction with Tangibility & Ubiquity 112
6.4.3 Proposition 3: The Effect of Adaptivity 117
6.4.4 Socio-ec(h)o Discussion 120

7: Synthesis of Cases 123
7.1 Proposition 1: Experience of Adaptivity 123
7.1.1 Awareness and Interpretation 123
7.2 Proposition 2: Adaptivity within Tangible and Ubiquitous Computing 126
7.2.1 Complexity and Collapse 127
7.2.2 Augmentation and Legibility 127
7.3 Proposition 3: The Effect of Adaptivity 128
7.3.1 Trust and Surprise 129
7.3.2 Control and Choice 130
7.4 Design Considerations 132
7.4.1 Awareness and Interpretation 132
7.4.2 Complexity and Collapse 133
7.4.3 Augmentation and Legibility 133
7.4.4 Trust and Surprise 133
7.4.5 Control and Choice 133

8: Conclusion 135

Appendices 138
Appendix A: Reading Glove Study Protocol 139
Appendix B: Kurio Study Protocol 144
Appendix C: Socio-ec(h)o Study Protocol 158

Reference List 165

List of Figures

Figure 1. Starting conceptual framework 26
Figure 2. The objects on the tabletop (left) and a reader using the system (right) 33
Figure 3. The structure of the ontology for one lexia 38
Figure 4. The tabletop screen in neutral (left) and recommender (right) states 39
Figure 5. Survey statistics from Reading Glove post-interaction questionnaire 45
Figure 6. Percentage of times recommendations were followed, by condition 55
Figure 7. Frequency distributions for two behavioural measures separated by condition (random = blue, intelligent = green) 56
Figure 8. Survey response on whether or not interactors felt they changed the story 64
Figure 9. Designers' understanding of the Reading Glove 72
Figure 10. Participants' understanding of the Reading Glove 73
Figure 11. The Kurio tools and tabletop (left) and a family using the system in the museum (right) 75
Figure 12. The information flow between Kurio system components. 78
Figure 13. Post-session questionnaire responses from Kurio 87
Figure 14. Post-session questionnaire responses from Kurio (pt 2) 94
Figure 15. Designers’ understanding of the Kurio system 98
Figure 16. Participants' understanding of the Kurio system 98
Figure 17. Participants using the socio-ec(h)o system 101
Figure 18. The socio-ec(h)o system diagram from (Wakkary et al., 2005a) 103
Figure 19. Socio-ec(h)o questionnaire response on learning 114
Figure 20. Socio-ec(h)o questionnaire response on helpfulness 114
Figure 21. Socio-ec(h)o questionnaire response on integration 115
Figure 22. Socio-ec(h)o questionnaire responses on the system 116
Figure 23. Socio-ec(h)o questionnaire response on responsiveness 119
Figure 24. Designers' understanding of socio-ec(h)o 121
Figure 25. Participants' understanding of the socio-ec(h)o 121
Figure 26. Participant’s experience of choice, control and creation 131

List of Tables

Table 1. Reading Glove research questions and data 36
Table 2. Weightings for matching themes 40
Table 3. Descriptive statistics from the Reading Glove study 46
Table 4. Kurio research questions and data 80
Table 5. Starting skill values based on age 82
Table 6. Example candidate ranking for a new challenge 83
Table 7. Effect of challenge completion on skill value 84
Table 8. Socio-ec(h)o levels 103
Table 9. Socio-ec(h)o research questions and data 106
Table 10. Average completion times (in minutes) with and without the manual 111
Table 11. Design concepts and considerations 137

1: Introduction

The vision of ubiquitous computing, first established by Weiser in 1991, is for information technology to become "invisible" and to vanish into the background when people become sufficiently accustomed to computation embedded throughout the environment (Weiser, 1991). In an imagined ubiquitous future scenario, he describes the daily life of Sue, a woman surrounded by embedded systems that unobtrusively prepare her coffee and newspaper, track and display information about her environment and family members, log her in and out of work, and facilitate her collaboration with office mates (Weiser, 1991). Each of these elements requires the computational systems around Sue to know something about her: where she is, what her preferences are, who she is connected to, or what she is working on. This knowledge of Sue as a specific individual rather than a generic user allows the technological systems surrounding her to adapt and personalize their functionality to suit her.   Where current interactive systems respond to users in a reliable and repeatable manner, treating each user the same, adaptive systems hold the promise of responding to each user as a unique individual (Brusilovsky and Millán, 2007). The appeal of this vision has sparked numerous research projects looking at how to imbue computational systems with enough intelligence and awareness to be able to learn about and adapt to their users.

Designing these intelligent, ubiquitous systems is not a straightforward task, however. When the technology is designed to be obscured, intelligent components can cause unexpected or unpredictable behaviours that make it difficult for users to understand what the system is doing. As computation is embedded in the environment and in normally non-computational devices, simply understanding what is and is not part of the system and how it is making decisions can become a source of confusion. Edwards and Grinter discuss a series of challenges for smart home systems, two of which are related to the transparency of system behavior (Edwards and Grinter, 2001). First, they discuss the possibility of an "accidentally" smart home when the gradual accretion of adaptive, networked devices will eventually result in a system of sufficient complexity that it will become unpredictable. Unpredictability and unintended interactions can also be issue in explicitly designed embedded systems. When the technology is designed to be hidden and invisible, unexpected or unpredictable behaviors can be hard for users to understand and fix. Second, Edwards and Grinter suggest that the “intelligent” component of intelligent environments can cause problems if the users do not understand the decision making process that the system follows (Edwards and Grinter, 2001). In particular, error correction and override mechanisms can be difficult to activate if users do not understand what is causing the error or feel the system “knows better” and is too complex to be adjusted.

Williams et al phrase it well when they say that the embedding of computation into everyday environments will:

> "reconfigure the relationship between people, objects, and space: first, by making spaces responsive to activities in ways not previously possible, and second, by presenting new challenge for the interpretation of actions and objects in space. In other words, how will people be able to make sense of computationally enhanced spaces and how will they be able to make sense of each other in those spaces?" (Williams et al., 2005)

Such spaces often involve new methods of interacting with technology, such as via tangible interfaces or ambient feedback systems, so users in the space must both learn a new form of interaction as well as interpret a new level of adaptive response. This presents a challenge in innovating in terms of both new technology and desired user experience.

1.1 Research Overview

The goal of this dissertation is to turn a critical eye on the notion of adaptivity, specifically within the realm of tangible and ubiquitous systems. In educational and workplace applications, adaptivity is typically task oriented and aimed at helping users achieve a particular learning or productivity related goal. This means that the adaptive mechanisms can be explicit, intervening directly with the user to offer them assistance or advice. In ubiquitous environments, however, the nature of the interaction with technology shifts. Computational elements are embedded in the environment or in smaller, handheld devices. Users may not be paying explicit attention to the system, and the activities taking place are less task oriented. Some of the most common uses of adaptivity in ubiquitous spaces are for leisure activities, such as museum guide systems that combine entertainment with educational or domestic systems that automate or anticipate common user behaviours. Since users of these systems are less focused on interacting with the technology itself, the goal of the system is to unobtrusively monitor the users and adapt itself to suit them in some way. The novelty of this kind of interaction is a significant issue in constructing adaptive components that work as intended, since little is known about how to design them and how people will experience them. To begin to explore this issue, I ask the following research questions in this dissertation:

1.1.1 Research Questions

1. What are the expected and actual benefits to the user experience that come from including adaptive components in ubiquitous and tangible systems?
2. How do the adaptive components support or complicate the ubiquitous and tangible system elements?
3. How do the goals and intentions of the designers of adaptive and ubiquitous systems compare to the actual experience that users have of the designed system?

1.1.2 Collective Case Study

To explore these questions related to adaptivity in tangible and ubiquitous systems, I have undertaken a collective case study that examines three different adaptive systems: the Reading Glove, Kurio, and socio-ec(h)o. The Reading Glove was an interactive storytelling system involving a piece of wearable technology that allowed participants to trigger story information by picking up objects. An adaptive component guided the reader through the story by recommending objects to interact with next. Kurio was a museum guide system that involved playing an educational game distributed across a set of handheld and tabletop devices. The adaptive component attempted to gauge the appropriate learning level in assigning tasks to each individual. Socio-ec(h)o was a group game played in an ambient environment, where teams of players had to coordinate their physical movements to solve riddle-based levels. Characteristics of the group's movement, location and position were used to adapt the system's ambient feedback system.

This series of case studies provides access to a wide range of different types of data about the experience of adaptive systems, including interview and questionnaire data from before and after the participants interacted with the systems as well as video recordings and system logs of their interactions. I use a mixed-method approach for collecting and analyzing this material, focusing on a qualitative analysis of the interview data into themes and categories, supported by quantitative evidence from the questionnaires and system logs. Triangulating an analysis in this manner allows themes and patterns to emerge that enhance the understanding of the phenomenon of adaptivity within ubiquitous and tangible systems. The intent of this research is to present a rich understanding of adaptivity, deeply rooted in the words and behaviour of the people who experienced them.

1.2 Document Organization

This dissertation consists of 8 chapters. Chapter 1: Introduction briefly sets up the context for the research and the key questions and methods used to investigate them. Chapter 2: Literature Review expands on the context for this research, looking at key ideas in tangible and ubiquitous computing as well as adaptive and intelligent system design. Chapter 3: Methodology describes the case study methodology used in this work. The next three chapters are individual case studies of each of the systems under study: The Reading Glove (Chapter 4), Kurio (Chapter 5) and socio-ec(h)o (Chapter 6). In Chapter 7: Synthesis of Cases I draw comparisons across all three cases, link the resulting analysis into the literature discussed in Chapter 2, and lay out a set of design considerations. Finally, Chapter 8: Conclusion summarizes the contributions of this research and the potential for future work.

2: Literature Review

My research questions deal with two main areas within the realm of human computer interaction and technology design: 1) tangible and ubiquitous computing and 2) adaptive or artificially intelligent systems. In this literature review, I begin by looking at the related areas of tangible computing and ubiquitous computing, identifying the current issues in the field and surveying the proposals for how to design for tangible and ubiquitous applications. I focus on the concept of embodied interaction and its grounding in the philosophy of Heidegger, which I use as orienting theory for this research. Next, I move to the field of adaptivity and look at what it means for a system to be adaptive or intelligent. I spend some time examining the idea of artificial intelligence and look at the work of Winograd and Flores, who also ground their understanding of designing intelligence in Heideggerian terms and whose ideas are also foundational to my research. Finally, I look at key existing systems that deal with tangibility, ubiquity and adaptivity and examine how they highlight the current advances and challenges within the domain.

2.1 Tangible and Ubiquitous Computing

The fields of tangible and ubiquitous computing are generally treated as separate, but related, with distinct major conferences and publishing venues as well as different key texts and foundational theories. Weiser's initial vision of ubiquitous computing, as described in the introduction, focuses on distributed systems that remain largely in the background of everyday life, but are aware of the unique needs and desires of the individual engaging with them (Weiser, 1991). Tangible computing, as described in the foundational paper by Ullmer & Ishii, focuses more on the power of connecting the physical environment to digital representations, allowing digital information to be manipulated through tangible interfaces (Ullmer and Ishii, 1997). In practice, however, more and more actual systems blur the boundary between these two research areas, as ubiquitous systems employ tangible interfaces or tangible applications rely on distributed sensor information and knowledge about individuals using them. Jacob et al attempt to sum up the last 20 years of interface and interaction design under the framework of "Reality-based Interaction", in contrast to direct manipulation/WIMP or command-line interaction (Jacob et al., 2008). They draw connections between ubiquitous computing, tangible computing, virtual, mixed and augmented reality, and mobile interaction, claiming that they all draw in some way on user's pre-existing knowledge of how to interact with the everyday world. The phrase “reality-based computing” did not catch on in any meaningful way, but the effort points to the way in which these terms are overlapping and entangled with each other. For the purposes of this dissertation, I will generally attempt to distinguish between tangible and ubiquitous aspects of the systems I am studying as well as the literature I review, but with the awareness that the boundary is blurry.

The desktop components of mouse, keyboard and screen have become so prevalent in the modern world that their use is almost taken for granted. The paradigms of both tangible and ubiquitous computing seek alternatives to this form of interaction. Ubiquitous computing focuses on embedded systems distributed throughout an environment, while tangible computing emphasizes physical manipulation that results in digital response. Both require users to learn a new way of interacting with the system, inviting them to move, twist, swing, and squeeze tangible devices, or simply gesture or walk around inside a sensor-laden space. There is no currently agreed upon best practices for designing these novel interactions so that they will work, in the sense of being learnable by the users and effective in their aims, whether those are defined in terms of specific functionality or a more general experience or feeling. While many novel interface designers attempt to design for “intuitive” and “natural” interactions, there is no tried and true method for achieving this goal (Hurtienne and Israel, 2007). Some have questioned whether an interface designed to be used “intuitively”, without any training, can have the complexity and flexibility necessary to truly support sustained or expert use, or if they will just remain toys or novelty items (Djajadiningrat et al., 2007). The challenge, then, is to find ways of combining existing patterns of everyday physical actions with innovative new ways of interacting with tangible, mobile and embedded technology, and to develop a general understanding of how to design these new interfaces. In the next two sections, I look at two key areas of work in tangible and ubiquitous computing: attempts to understand how people learn to interact with these new forms of technology, and proposals for principles that might guide how we design the technology.

2.1.1 Learning to Interact with Tangible and Ubiquitous Computing

Several researchers have looked at the role of metaphor in cognition and language as a way of guiding the design of novel interfaces in a human-learnable direction. Hurtienne and Israel tackle the question of how to design “intuitive” tangible interfaces head on, defining a system as intuitive "if the users' unconscious application of pre-existing knowledge leads to effective interaction" (Hurtienne and Israel, 2007). They propose a continuum of sources for pre-existing knowledge, starting with innate knowledge, through sensorimotor knowledge, cultural knowledge and finally learned expertise. They suggest that a productive way to approach designing for intuitive interaction is to start not with "objectively possible" actions but rather with "subjectively meaningful" ones. For this, they turn to the notion of image schemas, which are "abstract representations of recurring dynamic patterns of bodily interaction that structure the way we understand the world" (Hurtienne and Israel, 2007). Image schemas are extended from the physical to the abstract via metaphor, providing structures for thinking about and experiencing the world and thus can be used as guidelines for designing novel interactions. In a similar vein, Imaz and Benyon build on ideas from cognitive metaphor theory and image schema theory to propose designing with “blends”, which map elements from two input spaces into a new, integrated space containing its own emergent structure (Imaz and Benyon, 2007). They discuss the ways in which current technology design already makes frequent use of a handful of blends, such as viewing software systems as industrial plants with “pipelines” and other factory attributes, and they advocate for a more thoughtful and aware use of blending.

Svanaes and Verplank approach this issue from a different direction, starting not with a theory of cognition and metaphor, but rather with a study of the naturally arising metaphors and mental models that people create when playing with a set of interactive tiles (Svanaes and Verplank, 2000). The authors observed that participants made use of five fundamental metaphors: Cartesian space, state space, linear time, relational metaphors (human relations), and paranormal phenomena. Each of these reflects a different mental model that the users are applying to learn how to interact with the system. Understanding these mental models suggests different ways of designing a tangible interface to leverage the intuitive use of that model, or perhaps to explicitly design against it if the model leads to inappropriate intuitions about how the system works.

Djajadiningrat et al in some senses argue against the leveraging of naturally arising metaphors or intuitions about interaction; they propose that overcoming a certain amount of frustrating and unintuituve fumbling leads to greater pride and skill when that initial challenge is surmounted (Djajadiningrat et al., 2007). They highlight the neglected role of movement in traditional Human Computer Interaction (HCI) work and argue for a reassessment of physical action as both a pleasure in its own right and a way to ease cognitive overload by shifting the burden to bodily skill. Thus the goal in designing novel interactions need not be to make them easy or natural, but to make them pleasurable and physically engaging so that users strive to master them. Djajdiningrat et al provide a unique review of tangibility in the 20th century, classifying the different human-technology relationships as "machine cowboy", "analogue professional", and "digital hacker" (Djajadiningrat et al., 2007). They argue that there has been an increasing emphasis on cognition instead of on perceptual or motor skills, but that these physical skills can aid interaction in a number of ways. The process of acquiring physical skills can engrain physical procedures, allowing the flow of movement to assist in the learning new systems and contribute directly to the functionality of the system. Making better use of motor skills can also be beneficial because of the sense of challenge and pride inherent in acquiring them and the way they open up the interactional bandwidth, allowing control of multiple parameters.

Similarly, Klemmer et al.'s 2006 paper “How Bodies Matter” presents five themes for interaction design that arise from focusing on embodiment and physicality in order to understand how to approach the integration of physical and computational worlds (Klemmer et al., 2006). One of their core points is that GUI systems in general reduce all computational activity to the same set of physical interactions: moving a mouse and typing on the keyboard. In contrast, non-computational tasks like riding a bicycle or playing catch are characterized by a variety, richness, and complexity of physical action. They present five themes relevant to embodied interaction design: thinking through doing, performance, visibility, risk, and thickness of practice. For each theme, they present both theoretical ideas and example applications that show how the themes can be applied to interaction. While there are a large number of frameworks for characterizing tangible and embodied interaction, Klemmer et al's stands out in that it focuses not on technology or system characteristics but on the experience of such interaction, and on the ways in which embodied interaction is just a further exploration of common ways of interacting with the world.

Learning new ways to interact with technology is frequently a challenge and a burden, and the development of tangible and ubiquitous computing appears to promise to relieve some of that burden. However, there is clearly still a lot of work to be done to truly understand how people grapple with and come to understand a new method of interaction.

2.1.2 Designing for Tangible and Ubiquitous Computing

Shifting the focus from thinking about how the users will understand the system, a second major challenge from both tangible and ubiquitous computing is to develop frameworks for how to design these novel systems. Benford et al present the “expected, sensed, desired” framework for designing interfaces for “sensing-based interaction” that takes into account the increasing diversity of possible physical interface forms and the shift in design goals towards interfaces that are "pleasurable, aesthetic, creative, expressive" (Benford et al., 2005). "Expected" movements are those which users are likely to make in attempting to interact with the system, versus "less expected" ones which typically involve playing with or subverting the original use of the interface and "nonsensical" ones that are impossible to perform. "Sensed" movements are determined by whether or not the system is sensitive or responsive enough to measure them; movements may be "not sensed" when users deliberately or accidentally move out of range of the sensing equipment or the system breaks down in other ways. "Desired" movements are ones which are needed for the application to function, and may only partially overlap with expected and sensed movements (Benford et al., 2005). This framework provides a concrete structure to guide design thinking from both a functional and experiential perspective.

Because much of the aim of ubiquitous computing is to have systems that disappear into the background and are hidden from the user, the issue of how people make sense of these distributed systems is key. Bellotti et al lay out a framework for designers to apply ideas from human-human interaction to human-computer interaction in order to aid in the understanding of distributed, ubiquitous systems (Bellotti et al., 2002). They propose five questions to consider when designing how users will come to understand the system: 1) Address: how does the user address the system? 2) Attention: how does the user know the system is attending to her? 3) Action: how does the user take meaningful action? 4) Alignment: how does the user know the system has done the correct action? 5) Accident: how does the user avoid and recover from mistakes? (Bellotti et al., 2002). If the system functionality is not discernable in terms of these 5 categories, it will be hard for the user to come to grips with it.

Dourish's 2001 book *Where The Actions Is* lays out the foundation of his theory of embodied interaction (Dourish, 2001). His version of embodied interaction entails a synthesis of the fields of tangible computing and social computing with the philosophical notion of phenomenology. He argues that embodiment and embodied interaction are not the properties of a specific subset of interaction with technology but rather a way of thinking about how humans interact with the social and physical world every day. He provides two key definitions: "Embodiment is the property of our engagement with the world that allows us to make it meaningful" and "Embodied Interaction is the creation, manipulation and sharing of meaning through engaged interaction with artifacts" (Dourish, 2001). He breaks the notion of “meaning” down into three components: ontology, or how we individuate meaningful parts of the world; intersubjectivity, or how we share an agreement about what something means; and intentionality, or how meaning is directed at or connected to entities in the world. Intentionality requires the notion of coupling, which Dourish defines as "how an intentional reference is made effective" (Dourish, 2001). He connects coupling to the Heideggerian notions of present-at-hand and ready-at-hand, with the movement between these states representing different levels of engagement with the world and different couplings of meaning and action.

In his treatise *Being and Time,* Heidegger explores the nature of existence, or *Dasein*, commonly translated as “being-in-the-world” within his version of the philosophy of phenomenology (Heidegger, 1978, c. 1962). When describing how conscious entities engage with *Zeug* ("equipment" or objects in the world), he identifies two modes of being: *zuhanden* and *vorhanden*. *Zuhanden* is usually translated as “ready-to-hand”, and *vorhanden* as “present-at-hand”. Heidegger describes the modes thus: “1) the Being of those entities within-the-world which we proximally encounter—readiness-to-hand. 2) The Being of those entities which we can come across and whose nature we can determine if we discover them in their own right by going through the entities proximally encountered—presence-at-hand” (Heidegger, 1978, c. 1962). Both modes are connected to difference modes of “breakdown”: “The modes of conspicuousness, obtrusiveness, and obstinacy all have the function of bringing to the fore the characteristic of presence-at-hand in what is ready-to-hand” (Heidegger, 1978, c. 1962). Before breakdown, engagement with an object is seamless and it is ready-to-hand, working as an extension of the world and of the person using it. At the point of breakdown, however, the equipment becomes present-at-hand, an object distinct from the user which can be reflected upon. Fundamentally, Heidegger’s phenomenology is an argument for the fundamental and primary state of being-in-the-world, which is embodied and precedes the breakdown of the world in objects, subjects and other relations.

These notions from Heidegger have been interpreted by the design community so that technology is a kind of equipment, being either “ready-to-hand” for fluent use, or “present-at-hand” for reflection following breakdown. This cyclical process of engagement, separation, and re-engagement with equipment (and in particular, with tools and technology) is how people make sense of those objects and can come to act with as well as through them. Thus, says Dourish, within the realm of technology design, "the primary characteristic of technologies supporting embodied interaction is that they variously make manifest how they are coupled to the world, and so afford us the opportunity to orient to them in a variety of ways" (Dourish, 2001). As Dourish himself acknowledges, the transition from theory to practical design recommendations or guidelines is often imperfect. His work on embodied interaction does an excellent job of showing its lineage in existing ideas and practice and pointing towards its future potential as a perspective on technology design. However, applying these interesting, complex ideas to design in a concrete way is still an open question.

Svanaes takes a very similar theoretical approach to the question of interaction, focusing on the phenomenology of Merleau-Ponty (Svanaes, 2001). Svanaes argues against an understanding of context as a property of the objective external world, which relies on treating people as "Cartesian self-knowing entities detached from external reality" (Svanaes, 2001). He turns instead to Merleau-Ponty's conception of "being-in-the-world", where human perception is an active process of meaning creation that is pre-cognitive and embodied. Connecting this to technology, he describes how "through skill acquisition and tool use, we thus change our bodily space, and consequently our way of being in the world." Using a series of simple interactions involving colored squares and lights, Svaneas demonstrates how very basic changes to a space can create meaning and significance for the person perceiving it.

This reconfiguration of space through technology is a part of Weiser's foundational work on ubiquitous computing, which emphasizes the increasing ability of computation to disappear in to the background, becoming invisibly and seamlessly integrated into the fabric of everyday life (Weiser, 1991). It is this invisibility that amplifies understanding problems, so since this initial shaping of the ubiquitous computing vision, some theorists have pushed back against this notion of the disappearing computer. Chalmers and Galani propose the notion of "seamful interweaving" as a way of approaching distributed and embedded technology (Chalmers and Galani, 2004). They argue that while the overall goal of distributed computing may be a "seamless" interaction amongst heterogenous devices, the seams between the systems are in fact a crucial resource for the users' ability to understand, accommodate and appropriate the technology in order to integrate it into their lives. Like Dourish above, they turn to Heidegger's notion of "ready-to-hand" and "present-at-hand" states. They advocate for a greater understanding of the notion of "breakdown", which occurs when a tool fails in some way, occasioning the transition from a ready-to-hand state to present-at-hand state. This movement between the two states becomes an interpretive circle that supports the growth of understanding and the integration of novel technology (Chalmers and Galani, 2004). Systems must support the user's periodic need to "see the seams" of the system in order to achieve an understanding of how it works. In a similar vein, Tolmie et al propose that the ubiquitous computing goal of being "invisible in use" should be understood not as perceptual invisibility but as "unremarkability" (Tolmie et al., 2002). They conducted an ethnomethodological study of domestic life and found that routines played a crucial role in daily behavior. People may engage in complex behaviors involving coordination of multiple people and activities, but if it has become a regular routine, is regarded as an unremarkable activity (Tolmie et al., 2002). This work serves both as a caution against adding technology to support routines in the home in such a way as to make them "remarkable", thus disrupting their routine nature, and as a way of thinking about how technology can become integrated into daily life by becoming cognitively unremarkable rather than perceptually invisible.

Just as interacting with new technology requires a paradigm shift, designing for these new systems also requires rethinking how we approach technology design. Leveraging nuanced understandings of how people interact with the everyday world can lead to useful design insight.

2.2 Adaptivity and Intelligence

In the introduction I discussed how some measure of personalization or adaptive behaviour is key to the vision of ubiquitous computing. In many research projects containing an adaptive component, it is assumed that adaptivity is a straightforwardly good thing and that more personalized content or a more tailored interaction is something that the user will appreciate. While on the surface this may seem to be an unproblematic assumption, there is some reason to question it. Introducing intelligent components to a novel system complicates the task of the user in understanding how the system works. As with tangible and ubiquitous computing, we do not yet have a firm handle on how to design and build intelligent systems. In the following sections, I look first at what adaptivity is and what challenges it faces, and then step back and look at the field of artificial intelligence as a whole.

2.2.1 Developing Adaptive Systems

Adaptivity is used in a variety of computer applications, ranging from desktop tutoring systems to smart homes. Adaptive effects can appear to be random or nonsensical to the user, causing them to believe the system is malfunctioning or poorly designed (Edwards and Grinter, 2001). Frequently, adaptivity is pursued without a solid reason for explaining why it would be desirable, or how specific kinds of adaptivity can be achieved. Grounding adaptive design in established theories of how people differ from each other and how these differences might be addressed has met with only mixed success, such as with educational and information delivery systems aimed at adapting to a user's cognitive or learning style (Brusilovsky and Millán, 2007). Nevertheless, researchers remain quite optimistic about what adaptivity will contribute to novel systems. The book chapter "Ambient Culture" for the edited book *True Visions: The Emergence of Ambient Intelligence*, is disconcertingly utopian and pro-technology, envisioning a future full of unproblematic, ambiently intelligent systems supporting an educated and cultured human population (Marzano, 2006). How an adaptive system is actually experienced is frequently not a prime consideration when evaluating the success of a project. The adaptivity is assumed to be a benefit as long as it is implemented in a technically correct fashion Brusilovsky and Millán's survey of adaptive hypermedia and educational systems exemplifies this approach: the systems described are categorized in terms of the approach taken to knowledge representation & reasoning

(Brusilovsky and Millán, 2007). While this makes sense given the roots of user modelling and adaptivity in computer science and artificial intelligence research, this focus on the system specification holds the field back from developing a understanding of what adaptivity means experientially rather than computationally.

Brusilovsky and Millán define adaptation effects as the ability to "behave differently for different users" (Brusilovsky and Millán, 2007). This definition makes sense for many desktop-based adaptive systems, such as tutoring and help systems that try to suss out an interactor's experience level or learning stage and provide targeted feedback or lessons. A recent conference paper by Broy et al. examines some of the informal notions of adaptivity active within the fields of computer science and HCI and proposes the following definition:

> "A user experiences an adaptive system behaviour if the system reaction resulting from his inputs is additionally determined by some information about the environment… A system cannot be attributed to behave adaptively without explicitly relating to i) a subject (person or other technical system) and ii) the environment of use (modelled as context)." (Broy et al., 2009)

This definition of adaptivity applies more to ubiquitous and context-aware systems, where aspects of the space or context of use influence the computational response. However, it may not be broad enough to encompass desktop-based systems, which typically respond only to characteristics of the user built up over time.

These two definitions can be unified by bringing in the notion of explicit versus implicit interaction. A non-adaptive system responds only to explicit input from the user, including selections she makes and actions she takes in that moment. An adaptive system has other, implicit pathways for learning about the user. It can be designed to accumulate data over the course of multiple interactions, allowing it to infer something about the user's goals or abilities based on observed patterns. It could also take in information from other sensors and input devices in the environment and use that to make decisions about how to respond. Thus, the definition used in this dissertation is that a system is adaptive when it responds not simply to the user's explicit interactions, but also to implicit interaction patterns, environmental conditions, or other personal and contextual factors.

2.2.2 Tackling Artificial Intelligence

Looking at adaptivity in isolation from the large problem of intelligent systems in general is disingenuous, however, since modern adaptive systems are the outcome of a much bigger and larger project. The creation of artificially intelligent machines is a notion that has captured human imagination for some time, but it only became a serious research project in the 1950s, one which held much early promise that was not fulfilled (Dreyfus, 1972; Suchman, 1987). Early AI work emphasized symbolic processing and logical relations, believing that it was possible to specify in abstract, formal language all the knowledge of the world and how to reason about it. Several prominent researchers working in artificial intelligence and cognitive science have provided critiques of this traditional Cartesian approach to cognition, and proposed alternative formulations for understanding human cognition and how to emulate it computationally (Dreyfus, 1972; Winograd and Flores, 1986; Clark, 1996; Agre, 1997)

Dreyfus' well-known polemic against artificial intelligence provides a severe critique of the field as well as a detailed exploration of its underlying assumptions (Dreyfus, 1972). Dreyfus surveys AI work from 1957-1967, identifying the field's failures in the areas of language translation, general problem solving, pattern recognition, and language understanding. He suggests these failures result from faulty underlying assumptions about human intelligence, including: 1) the brain is not a digital computer (the biological assumption); 2) human behavior is not the result of an information processing mechanism acting on discrete inputs (the psychological assumption); 3) language use is not rule-based (the epistemological assumption); and 4) the data used for intelligent behaviour is not discrete, explicit and determinate (the ontological assumption). He proposes a set of alternative assumptions grounded in the work of Wittgenstein and Heidegger, as well as other philosophers, suggesting that AI needs to 1) deal with the role of the body; 2) look at context-based action as an alternative to rule-based behaviour; and 3) look at social and individual needs to explain behaviour. Much of the current work on embodied interaction can be seen as an attempt to address this challenge.

Winograd and Flores, in 1986, also facing the pessimism of the time about the chances of success at creating a human-level AI, proposed a slightly different take on how to integrate human-human interaction principles into human-computer design. They suggested framing human-computer interaction as a conversation between the designer and the users, mediated by the technology, and drew on speech act theory to understand how this conversation might be structured (Winograd and Flores, 1986). Winograd and Flores also looked at Heidegger's philosophy of phenomenology. They put forth a comprehensive critique of the state of artificial intelligence and human computer interaction work being done at that time. They draw together a number of disparate threads, from the phenomenological theories of Heidegger and Gadamer on how to understand "being in the world", to Maturana's biological theories on structural coupling and the relationship between organisms & their environment, and finishing with speech act theory's communicative structures of commitment and the illocutionary aspects of language. All these ideas are woven together to form an argument against a rationalist, objectivist conception of human action, technology, and design which rejects the notion that reflective, symbolic reasoning is the foundation for human cognition. They take a hard line against strong AI, claiming that human-level artificial intelligence is impossible because computers are incapable of committing to action via language, which is the foundation for human interaction. They see computers fundamentally as tools, but tools that can have a transformative effect. In the end, they put forth an argument for "ontological design", design which seeks to engage in "a philosophical discourse about the self-about what we can do and what we can be. Tools are fundamental to action, and through our actions we generate the world" (Winograd and Flores, 1986). While this book may not have completely dismantled the rationalist, objectivist approach to technology design as the authors hoped, it definitely interjected a new way of thinking about and talking about technology design into the discourse.

Despite these arguments in favor of an alternative approach to artificial intelligence, work on logical rule sets and narrow knowledge domains continued. In his 1997 book, Agre argues against what he calls the "mentalist" approach, a collection of theories rooted in Cartesian mind/body separation which includes both behaviorism and cognitivism (Agre, 1997). *Computation and Human Experience* is a critical reflection on the theory and practice of artificial intelligence and cognitive science research. He argues persuasively for a need to examine the foundations of technical work, exposing the metaphors at the centre of discourse about AI and cognition in order to understand recurrent problems and the ways in which the center and periphery of these fields are constructed. He discusses the ways in which current practice is dominated by the "mentalist" approach, a catch-all for theories founded in Cartesian mind/body separation, united by an agreement that human activity can be divided into that which happens inside versus outside the head. As an alternative, he proposes an "interactionist" approach, which views activity and thought much more holistically, as the interaction between people and their environment. He discusses in some detail how logic, dependencies, planning, representation, and other traditional AI concerns reflect a fundamental mentalist perspective and how they might be considered from an interactionist perspective. He draws on the phenomenology as well as his own observational work on everyday routines to argue for the situated, contingent nature of most human activity, with more abstract, internal-only thought being the exception rather than the rule. In the end, his goal is not necessarily to argue for any particular theory or way of instantiating theory, but simply to critically examine the discourse of AI so as to understand where certain assumptions are being made and to consider alternative assumptions that might lead in different directions.

Similarly, Clark's 1996 book *Being in the World* presents a detailed analysis of current cognitive science, artificial intelligence, and neuroscience research to construct an argument for a more embodied take on the philosophy of the mind (Clark, 1996). In particular, he argues against the traditional separation of mind from body/world, which privileges symbolic representations and processing. Although he does not reject internal representation entirely, he marshals many examples of how what we traditionally think of as "internal" cognition is in fact supported by or even occurring in the environment around us. He discusses, among other things, the robotics work of Brookes, Rumelhart & McClelland's connectionism, Hutchins' distributed cognition, Vygotskian psychology, the phenomenology for Heidegger and Merleau-Ponty, and the philosophy of Dreyfus and Dennett. In the end, he argues for a middle ground position between the extremes of all-representation and no-representation that he terms the "embodied mind". In this perspective, internal representations are primarily seen as "action-oriented", cognition is supported by the active structuring of the environment, and the human brain plus external scaffolding is what constitutes the "mind". Fundamentally, he argues, we confuse the mental with the conscious; while our consciousness does not extend outside the boundary of ourselves, our mental activity does. In one of the final chapters, he gives an interesting analysis of language as "a tool which alters the nature of computational tasks".

Winograd has also focused in on the relationship between language and design in his recent work, calling his theory of technology the “Language Action Perspective”

(Winograd, 2006). This theory has two key components: 1) that all information is communication and 2) that language is action. Thus the design of a new system is focused not on what information it contains, but on how it communicates that information and facilitates action by and between the users. Central concerns within the LAP are how novel applications deal with trust, commitment, and the negotiation of interpretation.

Leahu et al provide an interesting perspective on this debate by pointing out the ways in which the current challenges of ubiquitous computing parallel the difficulties encountered by classical AI work, which spurred the development of alternative "interactionist" AI techniques such as those listed above (Leahu et al., 2008). They advise ubiquitous computing researchers to learn lessons from the experience of the AI field, particularly in terms of avoiding the pitfalls around achieving "human-level understanding". They advocate instead that ubicomp work aim for situated, social, and even ad-hoc systems with just enough awareness and intelligence to "participate usefully and engagingly in the human world" (Leahu et al., 2008). This ties into the notion of seamful and unremarkable computing discussed previously, where the goal is not to confront users with an imposing and opaque intelligent system but rather to provide adaptive support that is comprehensible, heterogeneous, and suited to the user.

Although most systems using adaptive and intelligent techniques are not trying to replicate full human-scale intelligence, it is important to be aware of the fundamental questions of the field on how to approach knowledge representation and the act of reasoning. Many current theories of AI highlight the need for a better understanding of the embodied nature of intelligence, making tangible and ubiquitous computing a useful place to experiment with intelligent elements.

2.3 Designing User Experience

Studying and designing for "user experience" is a common research goal in the field of HCI, with almost as many definitions of user experience as there are projects. Having defined adaptivity as a system that responds to both explicit interactions and implicit input, I am most interested in the experiential aspects of adaptive systems that involve the user figuring out what the system is responsive to. This includes looking for exploratory behaviour while participants are interacting with the system, as well as asking them to articulate their understanding of the system in interviews. My concern is not to check if they are "correct" in terms of identifying how the system works, but to see if they notice the adaptivity, how they react to it, and how they talk about it. My goal is not to develop a cohesive theory of user experience, broadly construed, but to narrow in on the aspects of experience that relate to 1) learning a novel interaction paradigm such as a tangible or ubiquitous system and 2) understanding adaptive responses from such a system.

2.3.1 Related Work

There are a number of studies that have taken a similar approach to investigating the user experience of novel systems. Williams et al focused specifically on the nature of space in intelligent and augmented environments, looking at how people understand ubiquitous computing as a "spatially situated phenomenon" (Williams et al., 2005). They created an installation called SignalPlay, which involved a series of large, moveable props in a room, such as a set of oversize wooden blocks, chess pieces, and a lightsaber. Each of the props had a different effect on the soundscape of the room, and visitors to the space had to experiment with the objects in order to understand how they worked; no explicit instruction was given. From observing visitor interactions with the props, the authors identified three modes of object interaction used when learning how to control and interpret new interaction mechanisms: 1) iconic, where they interact in ways suggested by what the props represented; 2) intrinsic, where they interact based on physical characteristics of the objects; 3) instrumental, where they interact based on the effect it has on the system (Williams et al., 2005).

Dow et al conducted a qualitative-focused mixed methods study of an augmented reality version of the interactive storytelling system Facade (Dow et al., 2008). Using a combination of interview and video data analysis, they identified five styles of play exhibited by the study participants while interacting with the system. Similarly, Benford et al conducted a study of the mixed-reality game "Can you see me now?", where online players are chased through a virtual environment by "runners" using mobile technology to navigate a physical city (Benford et al., 2005). They collected observational ethnographic data of the player and their analysis ended up focusing on the ways in which the instability and uncertainty of the GPS and wireless networking components of the game affected the game experience. They turned this analysis of the experience of uncertainty into a set of design recommendations regarding how to help players understand their current “state of being” in terms of being connected and tracked within the game in order to manage uncertainty (Benford et al., 2005).

Ross & Keyson developed the Carousel project, a tangible sculpture for controlling the ambient atmosphere of a room (Ross and Keyson, 2007). The design goals of the project are to combine the notion of technology presence (as opposed to use) with expressive interaction (instead of task-oriented functionality). The authors describe the design and evaluation process for Carousel, a sculpture consisting of a rotating base and a series of moveable, attached flags. By adjusting the speed of the rotation and the position and orientation of the flags, interactors control the color and intensity of the room's lights, the ambient sound and projected video. Evaluation of the system showed that in general, the expressive nature of the control system was either natural or easily learned by the users. The authors do point out that each user had a slightly different interpretation both of the created atmospheres and of the best way to interact with the sculpture, highlighting the need for expressive systems of this sort to be capable of learning over time and adapting to individuals.

All of these studies show how a rich, qualitative-focused investigation of how people interact with computational systems can result in insight into the nature of these technology-enhanced experiences and how to design them.

3: Methodology

Unlike more established fields of research and inquiry, the interdisciplinary nature of the field of HCI and interaction design means that there is no set methodology or methods that can be picked up and used without thought. Consequently, HCI researchers tend to adapt and combine existing methodologies to create the one that suits their research work. Although this requires more intellectual work, the benefit of this process is that HCI researchers have a greater awareness of their methodological paradigm and are able to articulate the implications of and reasoning behind their method choices. The downside is that sometimes it becomes difficult to identify a clear path to validated results and specific answers to the research questions. In recognition of this, I will take some time here to detail the methodological approach of this dissertation, which is an exploratory, mixed-method collective case study situated within the pragmatic paradigm of knowledge creation.

3.1 Case Study

My methodological orientation is towards the paradigm of pragmatism, which focuses on using the most appropriate tools for any given research question, drawing on both qualitative and quantitative methods as necessary. Researchers within this paradigm typically employ mixed methods in their approach, and the knowledge they seek is rooted in understanding a specific problem and how to address it (Creswell and Plano Clark, 2007). Flavored by post-modernism, the pragmatist viewpoint aims to build useful knowledge that is deemed to be true "for the time being", but always open to re-evaluation.

A case study involves an in-depth exploration of a specific “bounded system” by collecting detailed data from multiple sources of information. This data is used to generate a rich description of the case, as well as an analysis of themes, issues, or patterns that emerge from it (Creswell, 1998). This method is ideally suited to complex, real-world phenomena where it is difficult to isolate specific variables or dependencies and when the boundary between the phenomenon and its context is not clear (Yin, 2002). The cases I present here are not strictly real-world phenomena, but rather explicitly designed research studies with recruited participants. However, each case is a bounded system of sufficient complexity that it would be impossible to perform controlled experiments on isolated elements. The adaptive components are interwoven with other aspects of ubiquity and tangibility in a manner that would be quite challenging to disentangle, making the more holistic case study approach an appropriate method for investigating this phenomenon.

Case studies are typically classified as a qualitative research method (Hancock and Algozzine, 2006), although they often involve collecting both quantitative and qualitative types of data. In this dissertation, the primary form of my analysis is qualitative in nature, identifying patterns and themes that arise in the conversations and interviews with study participants. I bring in quantitative data primarily for descriptive purposes and to provide context for the qualitative analysis. All of the data used in this dissertation is essentially secondary data; it was collected in the context of user studies aimed at exploring research questions different than the ones I am investigating here. At the time this dissertation research was conceived, two of the systems were no longer active projects, so there was no opportunity for active data collection using the systems. For this reason, a case study approach, which is often used to interrogate already-collected data and documentation, was chosen over an approach like ethnography, which requires access to an ongoing, observable situation. This is an exploratory case study, rather than explanatory or descriptive (Yin, 2002). Exploratory case studies investigate a phenomenon with relatively little theoretical framework in place, open to uncovering concept and issues revealed by the data. Explanatory case studies, in contrast, seek to establish a causal link between elements within the study and descriptive case studies seek to match a phenomenon to a predetermined descriptive theory. Exploratory case studies frequently rely on secondary data, as this research does, making it a good fit.

3.1.1 Chosen Cases

Each of the three cases share a core set of characteristics while also varying on a couple of dimensions. All three cases have a strong entertainment focus and involve tangible or ubiquitous interaction with an intelligent system. Socio-ec(h)o and Kurio are explicitly game-like, while the Reading Glove is more narrative in nature. Socio-ec(h)o provided content and cues via an ambient environment, while Kurio involved more focused interaction with hand-held devices, and the Reading Glove combined ambient sound with wearable interaction. The core adaptive components of both Kurio and the Reading Glove were based on individuals, while socio-ec(h)o focused more on group characteristics. The Reading Glove was used by one person at a time, and Kurio and socio-ec(h)o were used by groups of 3-5 people. Thus, while the choice of cases to study was constrained to a certain degree by what projects were available, I believe that they form a coherent and useful set to study. All the systems share key characteristics that warrant grouping them together while also being different enough to provide different perspectives on the phenomenon of ubiquitous, adaptive systems.

3.1.1.1 Socio-ec(h)o

The socio-ec(h)o project took place from 2004-2005. It involved a group game played with a responsive, ambiently intelligent environment. Groups of four players had to complete game levels by arranging their bodies and movements in a particular configuration, guided by riddle-like hints projected onto the walls. Ambient sound and lighting cues provided continuous, real-time feedback as to whether or not the group was moving closer to the correct solution. Published work on the system focuses on group and individual characteristics that contributed to game play, as well as elements of the sound design (Wakkary et al., 2005b; Droumeva and Wakkary, 2008; Wakkary et al., 2008a; Wakkary et al., 2008b). Since one of the main tasks of the game was to figure out what elements of group movement were needed to solve the puzzle, there was a fair amount of in-situ discussion between the participants about how to interact with the system and how to collaborate to solve it. These discussions are a valuable resource for beginning to understand how users make sense of the behaviour of an adaptive system. One of the original goals of the project was to use personality types to determine the adaptive response, but difficulties encountered in the design and implementation of the system prevented this mechanism from being fully developed.

3.1.1.2 Kurio

I was a researcher on the Kurio project from 2007-2008. The Kurio system was an adaptive museum guide system that invited family groups to play an educational game as a way of exploring a museum space. In Kurio, a family imagined themselves as time travellers from the future whose time map had broken, stranding them in the present. They had to complete a series of challenges that encouraged them to learn certain concepts from the museum in order to fix the map and continue their time travels. The interactive guide itself was comprised of a tangible user interface that was distributed over several tangible tools with different functions, a tabletop display, and a PDA. An adaptive user model component attempted to gauge the appropriate challenge level for each user and determined the optimum length of rounds for the group as a whole. Speed and accuracy of challenge completion, as well as explicit questions about how difficult the individuals found their assignments, were used to adjust the learning-level based user model. Published work for this project primarily examines the system log and questionnaire data, correlating user responses to the system with experience structuring factors such as number of challenges completed, length of time spent, and so forth (Hatala et al., 2009; Wakkary et al., 2009). This dissertation presents a comprehensive analysis of the semi-structured interview data as well as the participants' interaction within the museum which yields further insight into the participants' perception of the adaptive guide.

3.1.1.3 The Reading Glove

The Reading Glove project was a research project from 2009-2011, for which I was a co-lead designer and researcher along with fellow graduate student Joshua Tanenbaum. The Reading Glove was an interactive storytelling system centered around a wearable interface and a set of narratively rich objects. "Readers" of the story wore a glove containing an RFID reader and picked up tagged objects to trigger audio playback of story fragments. A tabletop display provided adaptive recommendations on which object to select next. Work has been published on the Reading Glove describing the process of designing the story and the interaction, and discussing some preliminary statistical and theoretical results (Tanenbaum et al., 2010a; Tanenbaum et al., 2010b; Tanenbaum et al., 2011). A full qualitative analysis of the interview and system use data is provided in this dissertation for the first time.

3.2 Research Questions

To investigate the phenomenon of adaptive systems, I started with the following research questions:

RQ1: What are the expected and actual benefits to the user experience that come from including adaptive components in ubiquitous and tangible systems?

RQ2: How do the adaptive components support or complicate the ubiquitous and tangible system elements?

RQ3: How do the goals and intentions of the designers of adaptive and ubiquitous systems compare to the actual experience that users have of the designed system?

3.2.1 Propositions

In case study research, research questions are frequently supplemented with specific assertions or theoretical commitments that will be used to structure the exploration of the data. Sometimes these are referred to as "propositions" which direct attention to areas that should be examined with the scope of the study (Baxter and Jack, 2008; Yin, 2009). Others term them "issues" and define them as "complex, situated, problematic relationships" that pull attention during analysis (Stake, 2005; Baxter and Jack, 2008). Issues and propositions are often posed in connection to the research questions, as a possible answer to one or more of them, and the data analysis can be structured to both support and refute the claims made at the beginning of the study. The propositions for this case study, each linked to a research question, are as follows:

P1: Designers have a greater belief in the benefits of adaptive components than the users experience.

P2: Designers believe that adaptive components can increase the ease of use or enhance learning or other experiential elements of ubiquitous systems, but in fact the adaptive components are more likely to add hidden complications.

P3: In tangible or ubiquitous systems that utilize intelligent techniques to provide adaptive system responses, the designer's intended adaptive effect differs significantly from the actual experience of the adaptive system by the users.

These propositions are based on the existing literature as well as my own personal experience as a designer and researcher.

3.2.2 Units of analysis

Each case under study is a specific design project with two embedded units of analysis, the system designers and the participants who experienced the system (Yin, 2009). To examine the system designers unit, I looked at evidence of the design process, including design documentation, the results of workshopping and iterative design activities, published papers, and study protocols. The goal of this analysis was to get a clear understanding of what the designers intended the system to do and what they were interested in exploring via their design work. For the purposes of this research, anyone who shaped the final outcome of the project is treated as a "designer", including technical developers, researchers who conducted preliminary studies and workshops, and people who contributed to the concept and interaction design process. For the second unit of analysis, the participants, I looked at the collected study data, including interviews, surveys, and records of system interaction. The aim of this analysis was to understand how the participants experienced the system and made sense of the novel interactive and intelligent components. Details on the types of data collected are provided in section 3.3 below.

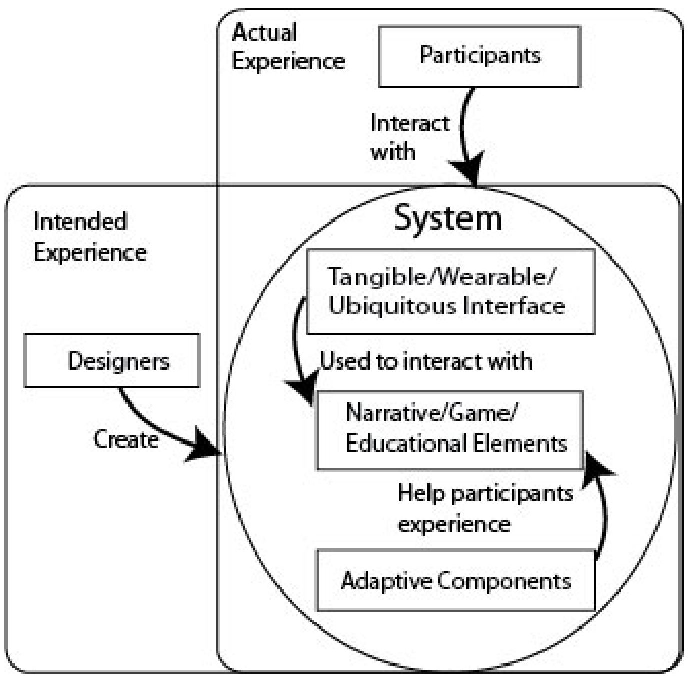


Figure 1. Starting conceptual framework

3.2.3 Conceptual Framework

Many forms of qualitative study design start with the development of a conceptual framework that explains the main elements to be studied and the presumed relationships between them (Miles and Huberman, 1994). At the start of the case study process, I developed an initial conceptual framework (Figure 1) for examining the relationships between the different elements of the case. The framework is broken into the two units of analysis, designers and participants, which intersect at the system itself. Designers create the system based on specific design theories and intended outcomes. Participants then experience the system, yielding the actual experience of the designed artifact. This framework is articulated, changed, and made specific to the individual cases over the course of the analysis; in particular, the relationship between the designers' intentions and the participants' actual experience is explored.

3.3 Data Collected

The bulk of the data collected was from studies that were not designed to investigate the specific questions I am asking, but were part of other studies exploring other (often related) areas of research. In each of the individual case study chapters, I identify the original research questions and methods for data collection, as well as discussing what data I found useful for my research. Here I give an overview of the kinds of data that were available across the three studies.

3.3.1 Semi-structured Interviews

Two of the three cases contain data from semi-structured interviews conducted with participants following their interaction with the system; the socio-echo study administered only a survey after game play. For Kurio and the Reading Glove, the post-interaction interviews were recorded and the dialogue transcribed for analysis. The interview data was analyzed for information about the experience participants had of the systems: what kind of sense they made out of it, how they arrived at that understanding, and how they felt about it.

3.3.2 Observation of System Interaction

Video recordings of participants interacting with the systems were collected in all three cases. While a full coding of the video was not undertaken, the videos were annotated with broad categories of behaviour and ways of interacting with the system. In socio-ec(h)o and Kurio, multiple people used the system together and the dialogue between participants was transcribed and analyzed to see how an understanding of the system was constructed collaboratively over time. Since the Reading Glove only supports one interactor at a time, no conversation was recorded during the system interaction.

3.3.3 Questionnaires

All three cases had pre- and post- interaction questionnaires involving mostly Likert-scale questions on different topics. Pre-interaction surveys tended to ask basic demographic questions and probe for certain key characteristics, such as experience with similar systems, familiarity with museums, or personality types. Post-interaction surveys gathered quantitative data about the experience of using the system, asking participants to rate how much fun it was, how easy it was to use, and so forth. This survey data provides descriptive statistics and other framing information for interpreting the qualitative results of the within-case analysis.

3.3.4 System logs

System logs from all three systems provide details about specific features of the experience, allowing the extraction of information about how long the interaction lasted, how many tasks or game challenges each person completed, what they listened to and in what order, and so forth. Details about the adaptive system are also recoverable from the system logs, so specific system behaviours can be interrogated to see what triggered them.

3.3.5 Design Documents

Design documents were collected for each of the three systems. These include a wide variety of material: notes from initial brainstorming sessions, scenarios that imagine the interaction flow, workshops to investigate specific elements of the design, early prototypes and sketches, wireframes and mock-ups of screens and system architecture, and published and unpublished papers. This data was used to frame an understanding of the aims of the designers and how they might have shifted over the course of development work.

3.4 Analytical Strategy

This is a mixed method study with a predominately qualitative focus. To answer the first two research questions and propositions, my primary analytic strategy was a qualitative analysis of the participant's descriptions of the system and their experience with it, taken from the interviews following their interaction with the system or the conversations they had while using the system. These transcripts were coded and then categorized into themes and related concepts to allow for a deep understanding of the experience from the participant's point of view (Miles and Huberman, 1994; Corbin and Strauss, 2008). Working in the qualitative data analysis software atlas.ti, I coded each of the interviews a first time by reading through them and highlighting interesting concepts. I also kept separate analytical memos about ideas or connections between concepts that occurred to me while coding. Next I sorted these codes, discarding some that were weakly supported, combining others that overlapped, and looking at the possible interconnections between the concepts. Working with the most interesting and well-grounded codes, I iterated through a couple of different ways of grouping and categorizing the codes. I looked at all the quotes associated with each code and wrote a summary description of that concept, using selected portions of the participant's actual words to explain each one.

Finally, I took each of these detailed descriptions and memos and wove them together into the an analytic narrative, which is presented using quotes to support the analytical categories. The goal of this form of analysis is to produce a thick, rich description of how participants experienced each of the systems under study and to begin to build some higher-level analytical categories that apply more generally to adaptive, tangible and ubiquitous computing systems. The results from this analysis are supported by data from the surveys, system logs, and video recordings of the participants interacting with the systems. Some of these supporting results are quantitative in nature, including descriptive and correlational statistics.

To answer the third research question and associated proposition, I combined the participant-focused analysis described above with the description of the design of the systems. This system design description focuses on developing an understanding of the designers' intended participant experience and their design process. This part of the analysis is drawn from published papers and internal design documentation produced over the course of prototyping and workshopping the systems, as well as my personal knowledge from being a researcher on two of the three systems. The design intentions are compared to the actual experience of the system.

The Reading Glove analysis provides the bulk of the argument presented in this dissertation, while the Kurio and socio-echo analyses are comparatively smaller and function to complement the main Reading Glove findings. The reason for this disparity comes from the nature of the studies undertaken with the systems. With the Reading Glove, I was able to design and conduct a study aimed specifically at exploring the research questions that this dissertation is concerned with. With the Kurio and socio-ec(h)o data, I was working with secondary data from studies that were collected with different research goals in mind. While data from these two cases still provide useful insights into the questions I am asking, portions of the data are less relevant. In each of the individual case studies below, I identify what data I have used and what I have set aside and why.

3.5 Validity

Qualitative and mixed method research does not have a clear test for validity the way statistical quantitative research does. Creswell & Plano-Clark define validity in mixed methods studies as “the ability of the researcher to draw meaningful and accurate conclusions from all of the data in the study” (Creswell and Plano Clark, 2007). There is a set of commonly used techniques for establishing the validity of non-statistical research findings. This dissertation relies on three of these techniques: clarification of bias; rich, thick description; and triangulation (Creswell, 2003). Here I discuss my strategies for implementing each of these throughout the analysis and presentation of findings.

3.5.1 Clarification of Bias

Bias can be introduced into research through both the researchers and the participant group that is studied. Qualitative research is always to a certain degree subjective, in that is relies on a researcher analyzing and interpreting the results based upon their own experience and inherent orientations. Rigorous qualitative researchers will state their personal viewpoint and acknowledge its unavoidable presence in the analysis and interpretation that follows (Corbin and Strauss, 2008). In the analysis that follows, I used data from three separate studies in order to develop a set of constructs that describe and categorize the perception of adaptivity in ubiquitous spaces. However, each study was constructed with its own set of guiding principles and questions behind their design. For two of the cases, Kurio and the Reading Glove, I was involved in the design and implementation of both the system itself and the study that generated the data. In the individual sections of each of these cases, I describe the motivations behind each of the system's design and the research questions the studies intended to answer in order to explicate the bias inherent in the design of the systems and my own position as a researcher on those projects.

For both the Reading Glove and the socio-ec(h)o project, the population that participants were drawn from were largely technology-savvy undergraduates and graduate students at the School of Interactive Arts and Technology at Simon Fraser University and the Masters of Digital Media program at the Centre for Digital Media. The participants therefore have some inherent pro-technology biases as well as a generally more sophisticated understanding of technology use and design issues than the average person. In the Kurio study, participants were families from the Vancouver and Surrey areas of British Columbia, so they had less of a strong bias towards technology. Another potential issue with collecting data for this study is that the novelty of ubiquitous systems leads to generally positive results to any questions, since participants find it an interesting experience no matter whether or not it is working as intended. They have no baseline to compare against due to the unique nature of the environment. Respondents in interviews frequently say complimentary things about the experience because they know they are talking to the designers of the system. I have attempted to highlight areas where this novelty bias is evident.

3.5.2 Rich, Thick Description

The use of rich, thick description is a technique seen in ethnographic and phenomenological research to capture and evoke the details of a particular setting or situation (Creswell, 2003). Detailed descriptions of this type help convince the reader of the validity of the findings by giving them clear insight into the data so they have a better ability to judge the conclusions reached by the research. In this dissertation, I provide rich, thick description of the participant experience of each of the different systems, and make frequent use of verbatim quotes from the participants as a technique for grounding the reader in the data and demonstrating validity.

3.5.3 Triangulation

Triangulation involves the use of multiple data sources, methods, and analytical techniques to converge on a set of findings (Creswell, 2003; Creswell and Plano Clark, 2007). In this dissertation, I triangulate my results in multiple ways. First, I use three cases to build my analysis across distinct systems and groups of participants. Second, within each case, I collect and analyze multiple streams of data, as described in section 3.3 above. Finally, I apply both qualitative and quantitative methods to the data, resulting in a wide range of evidence to support my conclusions.

4: Case 1: The Reading Glove

The Reading Glove project is a multi-year research endeavor undertaken by myself and PhD student Joshua Tanenbaum with the support and input of our supervisors Marek Hatala, Ron Wakkary, Alissa Antle, Jim Bizzocchi and Magy Seif el-Nasr. The Reading Glove explored research questions around tangible interaction, interactive narrative, and adaptivity. The system analyzed here is version 2.0 of an earlier iteration of the project. The first version, discussed in (Tanenbaum et al., 2010a; Tanenbaum et al., 2011), consisted of a glove-based reader and a set of tagged objects used to access a non-linear story. The most recent version added an intelligent recommender system and tabletop display (See Figure 2). These additions assist interactors in navigating the narrative while also allowing the study of user perceptions of adaptivity.

Figure 2. The objects on the tabletop (left) and a reader using the system (right)

4.1 The Reading Glove Description

4.1.1 Interaction and Story

Interaction with the Reading Glove system is straightforward. The “reader” puts on a soft fabric glove and begins by picking up one of the objects sitting on a tabletop. This tabletop displays pictures of each object arranged in a rectangle (see Figure 4 below). When the palm of the glove registers the tag on the object, a segment of recorded audio narration is played back over the speakers. Several seconds before the clip ends, the tabletop display delivers a set of recommendations on which object to pick up next by enlarging and brightening photos of the recommended objects. The reader can choose to follow the on-screen advice or not. Each object has two clips of audio narration associated with it, so the reader must engage with each object multiple times to uncover all the story fragments.

The story embedded in the Reading Glove system was developed based on the objects, which were picked to fit a certain historical aesthetic. Other aspects of this aesthetic are echoed in the background image of the tabletop display and in the table itself. The plot of the story revolves around a British spy operating in French-occupied Algiers around the turn of the 20^{th} century. The narrative traces the spy's discovery that his cover has been blown and his unraveling of how this came about. The uncovering of facts in the narrative mimics the uncovering of story fragments that the readers perform with the objects. Thus the puzzle-like nature of the story and the interaction support and reinforce each other, with the adaptive components providing guidance in putting the puzzle together.

4.1.2 Technical Details

The central component of the system is the Reading Glove itself, a soft fabric glove containing an Arduino Lilypad microcontroller, an Innovations ID-12 RFID reader, and an Xbee Series 2 wireless radio. Interactors pick up objects associated with the story, each of which has been tagged with an RFID chip. When the RFID reader in the palm of the glove detects a tag, the tag ID is communicated wirelessly via the Xbee radio to a second Xbee unit connected to the serial port of a laptop. The serial data is read into a Java program in Eclipse which processes the tag activation and triggers the audio playback of a specific "lexia": a pre-recorded story fragment associated with the object.

4.2 The Reading Glove Study

In the fall of 2010, the Reading Glove was the focus of a mixed-methods user study with 30 participants who used the system individually in roughly one hour long sessions. The study collected a wide variety of data, including pre- and post-interaction surveys, a post-interaction interview, video of the participants using the system, and log data generated by the system itself. The user study of the Reading Glove asked the following research questions:

1. How do interactors respond to the adaptive system?
2. How do the responses differ across the different types of adaptivity?

The goal of the study was to explore the user response to adaptivity rather than to evaluate the strict effectiveness of the adaptive mechanisms. One of the primary interests was to understand how the users made sense of a system that responded to them in intelligent or intelligent-seeming ways when no explicit information was provided about what the system would be reacting to.

4.2.1 Study Protocol

The study consists of three stages: a pre-interaction phase where participants took a demographic survey and listening composition test, an interaction phase involving both training and free play with the system, and a post-interaction phase consisting of an interview and questionnaire about their experience. Participants were randomly assigned to one of three conditions, corresponding to three different versions of the system: two different intelligent recommender systems, and one random recommender. The details of these three versions are given in section 4.3.3 below. They went through a brief tutorial on how to use the glove by interacting with a set of training objects, and then were given time to play with the full system. They were not told which condition they were in, and the only description they were given of what the system did was as follows:

> “You will be interacting with this collection of objects. Interact with them until you feel like you understand the story. The images on the screen can help guide you through the story. You are free to handle, play with, and move the objects around as much as you like. You may take as long as you like. Let us know when you are ready to stop.”

Participants received a $10 gift card to a local coffeeshop in exchange for their time.

4.2.2 Data Collected

As discussed in Section 3.3, several different forms of data were collected from the user study described above as well as the design process. Table 1 shows how each research question was broken down into smaller investigations using specific parts of the Reading Glove data. The interview questions and surveys given to the participants are in Appendix A.

Table 1. Reading Glove research questions and data

Research Question	Data Collected
1. What are the expected and actual benefits to the user experience that come from including adaptive components in ubiquitous and tangible systems?	
Do the participants find the system basically usable and enjoyable?	Post-Questionnaire & Interview
Do participants notice the differences in the recommender across the 3 conditions?	Interview & Questionnaire
How do participants describe the system and the adaptive components in particular?	Interview
What were the designers' intentions in terms of participant experience?	Design Documents & Papers
2. How do the adaptive components support or complicate the ubiquitous and tangible system elements?	
How do participants interact with the objects and glove?	Observed Behaviour
What do participants think about the objects and the glove and the physical interaction?	Interview & Questionnaire
What were the designers' intentions in terms of the tangible interaction?	Design Documents & Papers
3. How do the goals and intentions of the designers of adaptive and ubiquitous systems compare to the actual experience that users have of the designed system?	
What was the goal of the designers for the adaptive components?	Analysis of Proposition 1 and 2
How do the intentions and the actual experience compare to each other?	Analysis of Proposition 1 and 2
If the intended benefit is not seen, how is adaptivity experienced?	Interview & Questionnaire

4.2.3 Units of Analysis

The first unit of analysis in studying this system is the data collected about the designers and their intentions while designing the system. The Reading Glove was primarily designed by Karen and Joshua Tanenbaum. Both took part in the development of the glove-based interaction model and the adaptive feedback system. Joshua was primarily responsible for the construction of the electronic components in glove, while Karen handled the programming of the glove communication and the reasoning engine that drove the adaptive recommender. They collaborated on the writing of the object-based story. The system was designed over the course of 2 years, from 2009-2010. To perform the designer focused analysis, data from published research papers and design documentation such as sketches and previous system iterations was used.

The second unit of analysis is the data collected from the participants of the study. Of the 30 participants run through the study, 19 were men and 11 were women. Ages ranged between 23 to 55 years old, with the median at 31 years. All were graduate level students, 20 working on their Masters degrees and 10 working on PhDs. Most were from media and technology oriented programs. Participants were asked to self-rank themselves on their English fluency, with 18 reporting to be native speakers, 7 reporting as fluent speakers and 5 as advanced speakers. All participants were administered a listening comprehension test at the start of the session as well, to check for English comprehension issues, and all passed. To perform the participant focused analysis, data from the study interviews, video recordings, questionnaires and system logs was used.

4.3 Adaptivity in the Reading Glove

The core adaptive component in the Reading Glove is the recommender system displayed on the tabletop screen. Each time an object is picked up, the glove triggers the reasoning engine to generate a set of recommendations that will be shown to the interactor when the audio clip associated with the object nears its completion. The reasoning engine is a rule-based expert system written in the Jess language. The reasoning component relies on an OWL (Web Ontology Language) ontology that encodes semantic knowledge about the story content. The recommendations act as a kind of “expert storyteller”, leading the reader through the narrative while still allowing for the expression of personal choices and interaction. To achieve this “expert” nature of the recommendations, an ontology was constructed to function as the knowledge base for the reasoning engine. The ontology encodes elements of knowledge known to the authors of the story: themes that run through the story, how the objects and lexia relate, how important each particular lexia is, what scene it is part of, and what chronological position it is in.

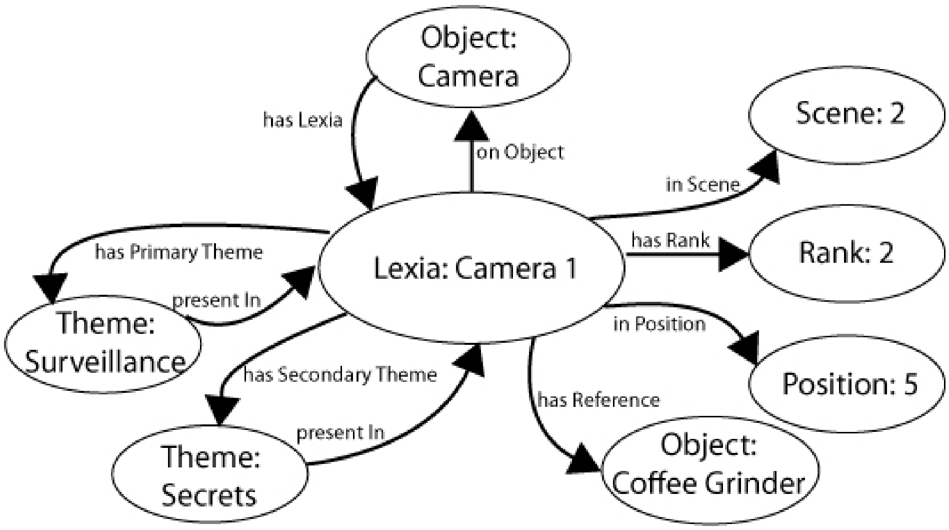


Figure 3. The structure of the ontology for one lexia

4.3.1 Reading Glove Ontology

The ontology has 5 classes and 11 object properties that link classes together in a directional relationship. The object and lexia classes have a reciprocal relationship, with each item in the object class (e.g. the physical object Telegraph Key) linking to two entities in the lexia class (e.g. the sound files Telegraph Key 1 and Telegraph Key 2) and each lexia connecting back to the object. See Figure 3 for an example of a specific lexia in the ontology, *camera2*, on the object *camera*. The lexia class also has a set of non-reciprocal object properties connecting each sound file to different pieces of information. The *hasRank* property indicates how important the lexia is to the overall narrative, as determined by us as the story authors. Rank varies from 1 to 9, with 1 being the most important. The *inScene* property indicates what scene each lexia was part of; there were 4 scenes determined by changes in the location of the narrative. The *hasReference* property was only active for some lexia, those which contained a direct reference to another object within the text of the audio clip. For example, the camera1 lexia includes the sentence “I made certain to lose myself in the chaotic traffic of one of the city’s open air markets before stopping to inspect the coffee grinder.”, so in the ontology the lexia is linked to the *coffee grinder* object. Finally, each lexia is associated with 2-3 themes present in the story, such as “surveillance” or “disguise”. This relationship was also represented reciprocally between the lexia and theme classes with the properties *hasPrimaryTheme* and *hasSecondaryTheme* connecting lexia to themes and *presentIn* connecting theme to lexia.

Figure 4. The tabletop screen in neutral (left) and recommender (right) states

4.3.2 Reading Glove Recommendations

The Jess rules use the knowledge base of the ontology to recommend a set of three objects that will be most likely to advance the interactor's understanding of the story. The recommendations appear on the table several seconds before the end of the lexia. This delay is intended to focus attention on the story and objects rather than the display, encouraging the user to listen to the full lexia rather than just skip ahead. During most of the lexia playback, all 10 objects are visible on the screen in small, semi-transparent boxes. When the recommendation system kicks in, the pictures of the recommended objects grow in size and become fully opaque (See Figure 4). The display remains in this state until another object is picked up, at which point in reverts to the neutral state.

4.3.3 Reading Glove Recommender types

Three separate versions of the recommender were developed: a story content recommender, a user model recommender, and a random recommender.

4.3.3.1 Story Content Recommender

The story content recommender uses encoded knowledge about the narrative to recommend three objects that will be most likely to continue the story in a coherent and helpful way. The interactor can choose any object to start the story, after which the recommendation system begins to assist based on their ongoing choices. Each of the three recommended objects are chosen based on a different set of criteria: Theme, Importance, or Position. The last lexia chosen by the interactor is used as a "seed" to the recommendation system, generating a set of weights that rank all other available “candidate” lexia. The highest ranked candidate after all the weights are calculated is the one recommended for each criterion.

Theme. The Theme criterion uses the ontology-encoded themes of the seed to evaluate the candidates based on how closely their themes matched. Each lexia has two themes, primary and secondary. The weighting of the candidates is based on whether both the theme and the theme type match the seed. Table 2 gives the weights for ranking seed and candidate themes. If the seed lexia text contains a direct reference to the object of the candidate lexia, this contributes an additional 50 points. After all the weights are calculated and summed together, the candidate with the highest sum is designated the Theme recommendation.

Table 2. Weightings for matching themes

Seed \ Candidate	Primary Theme	Secondary Theme
Primary Theme	50	20
Secondary Theme	30	40

Position. The Position criterion looks at the chronological order of the lexia and favors candidates that would either move the story forward or fill in the backstory. The highest weights are given to candidates that are 1-4 positions past the seed, while medium weights are given to candidates positioned prior to the seed location, and low weights are given to candidates 5 or more ahead of the seed. If the seed lexia is in position 5, the candidate in position 6 would have a weighting of 50, 7-9 would be weighted 30, 1-4 would be weighted 20 and 10-20 would be unweighted. This prioritizes continuity of the story and deprioritizes leaping ahead to the end of the narrative. The candidate with the highest weight at the end of this calculation would be designated the Position recommendation.

Importance. The importance criterion looks at what the most important pieces of the story are and favors recommending the most crucial information. The importance weights combine information about what scene the fragment is in and what the overall rank of each lexia within the scene is. Candidate lexia in the same scene as the seed lexia are given a weight of 50 while candidates from different scenes are unweighted. Next, importance weightings are assigned based on rank, with rank 1 = 45, 2 = 40, 3 = 35, and so on down to rank 9 = 5. The ranks of both of the lexia on an object were summed together with the scene weighting for each candidate lexia. This mechanism was necessary in order to uncover lexia on objects that had not yet been interacted with. For example, an object might have a lexia with rank 8 as the initial state and a lexia with rank 2 as the secondary state. Although the second lexia is very important, if the first lexia is never listened to, the other one will never become available. Summing the importance for both lexia on the object allowed unimportant lexia to be recommended in order to get access to the more important pieces also on the same object. The scene and rank weights were summed and the candidate with the highest sum would be designated the Importance recommendation.

After all these calculations are completed, the recommendations generated by each of the criteria are presented to the user on the tabletop. Each recommendation has a subtly colored border indicating which criterion it represents, with blue for Theme, green for Position, and red for Importance.

4.3.3.2 User Model Recommender

The user model recommender is built on top of the story content recommender, adding additional weights based on the specific actions the user takes with the system. It promotes lexia that have not yet been listened to by adding weights to the candidate calculations described above. The user model also tracks which of the recommendation streams are followed if the user selects from one of the three highlighted objects. If the user consistently follows one recommendation criterion over the others, the user model component will begin to push that recommendation to the user earlier, before the other two.

4.3.3.3 Random Recommender

The random recommender is simple and straightforward: three objects are selected at random from the set of available objects using a random number generator in Processing, and are presented to the user via the tabletop display. The colored borders around the pictures are maintained, but are essentially meaningless.

4.4 Reading Glove Analysis

4.4.1 Proposition 1: Intended Benefit vs Actual Experience

The first proposition that I am investigating with this case study is that *Designers have a greater belief in the benefits of adaptive components than the users experience*. To address this proposition, I examine data related to each of the two units of analysis: designers and participants. I begin with the designers, using my personal experience of the design process and looking at the collected design documentation and published work to identify what the intended benefit of the adaptive components were. Then I look at the user study data to see what the actual experience of the system was like for the participants.

4.4.1.1 Designers: Intended Benefit of Adaptivity

In creating the Reading Glove, the primary goal was a simple, direct interaction with objects that tell a story. Allowing interactors to select from amongst all available objects meant that they would encounter the story out of order and have to piece it together. Making the story non-linear was done not to confuse the reader pointlessly, but rather to engage interactors by challenging them to put it together, to assemble the narrative physically as well as mentally. The adaptive elements of the tabletop screen and recommendation engine were developed as a guidance system to support the interactors in exploring the story and piecing it together effectively. An iterative design process across several versions of the system helped to develop a story and a recommendation system that allowed for non-linear encounters with the narrative (Tanenbaum et al., 2010a; Tanenbaum et al., 2011). Here I explore part of this design process to show why specific choices were made and what their intended effect was.

The first version of the system had 16 story fragments, or *lexia*, across 10 objects. Six of the objects had two lexia associated with them, while the remaining four objects had only a single lexia. For objects with multiple lexia, the designers faced a dilemma of how much authorial control to exert over the reader's experience of the different fragments. If the system was programmed to play these in chronological order, this design choice would structure the way in which the story was presented, at least at an intra-object level. There was a concern that doing this would discourage interactors from exploratory interactions with the objects by quickly revealing the limitations of the available options. For the first iteration of the story, the decision was made to instead have the associated lexia presented at random (Tanenbaum et al., 2010a). The random triggering of the lexia on an object meant that it was much more likely that an interactor would miss a fragment of the story; however, this decision rewarded sustained interaction and exploration on the part of the reader.

A pilot user study with this version of the glove was conducted, with 7 participants exploring the objects and the story for between 10-15 minutes. The clearest outcome from the pilot study was that the random access of the objects with the multiple lexia was problematic. None of the 7 participants heard all of the fragments, because they did not know which objects only had one lexia, and which just happened to play the same clip multiple times rather than alternating the multiple clips available. This variability in playback prevented some of the participants from being able to make sense of the story or how the system worked. Based on this preliminary feedback, there were a handful of design changes made to the glove and the system. Four additional lexia were composed for the story, so that there were a total of 20 lexia and each object had two lexia associated with it. The lexia activation code was redone so that the choice between the two lexia on each object was no longer random, but rather flipped back and forth regularly between the first and second lexia. The first time an object was picked up, the chronologically earlier lexia was played. This enforced a certain amount of chronological ordering as it was impossible to hear the second lexia until the first had been heard.

A second preliminary study was conducted with 10 participants, where they interacted with the system and then gave a short interview and filled out a survey. The question in the interview and survey focused on two basic areas: their understanding of the story and their experience of the glove and the objects. There were two core results coming out of this study. One was that participants were hesitant about moving the objects around; they appeared to need to be given permission to interact with and manipulate the objects. The second was that the lexia-related changes solved the problem of encountering the same clip over and over, but had other effects. Although there had been some concern that ordering the lexia chronologically would make the system too transparent, this did not appear to be the case. Participants found it challenging to remember which lexia were associated with each object and to assemble them mentally into the correct order. This was likely due to the fact that there were several additional fragments to remember and track, and each object had two lexia that were continually alternated, rather than one lexia repeating continuously to form a strong association.

For the final version of the system, the adaptive component was added. Via the tabletop display, readers were provided with optional assistance in navigating the non-linear narrative. The goal of the adaptivity was to have it act as a kind of “expert storyteller”, using knowledge of what had already been listened to in order to suggest the next best lexia. This guidance was not intended to undercut the reader’s ability to explore and choose freely, however, so in most cases, a range of 3 objects was suggested rather than just one, and the display could be ignored entirely with no consequences. The issue of interactors feeling hesitant about moving the objects was addressed via explicit encouragement to rearrange the objects during the study session, although this had mixed results.

4.4.1.2 Participants: Actual Experience

With a better understanding of the design process and the decisions that went into creating the system in place, I now turn to an analysis of the actual experience of the participants in the 30 person study described in section 4.2 above. The first element I looked at was the overall experience participants had, to establish a baseline. Did they find the system basically enjoyable and functional, or were there serious usability issues that would prevent using the data to explore deeper questions? At the very end of the user study session, participants were asked to fill out a short Likert-style survey consisting of 8 questions (See Appendix A). The questions were paired as negative and positive versions of 4 basic concepts, with participants asked to rate them on a 5-point scale consisting of “Strongly Disagree”, “Disagree”, “Undecided”, “Agree”, “Strongly Agree” and “No Answer”. The pairs were presented in a jumbled order to the participant, but are listed here by concept for ease of reading. The first 3 pairs are discussed here, while the final pair is discussed in section 4.4.3.2.1.

- Ease of Use: The system was easy to use; The system was hard to use
- Enjoyment: The system was enjoyable to use; The system was confusing to use
- Experience Again: I would not be interested in experiencing another story like this; I would like to experience another story this way
- Story: The actions I took didn't influence the story; My actions changed the story

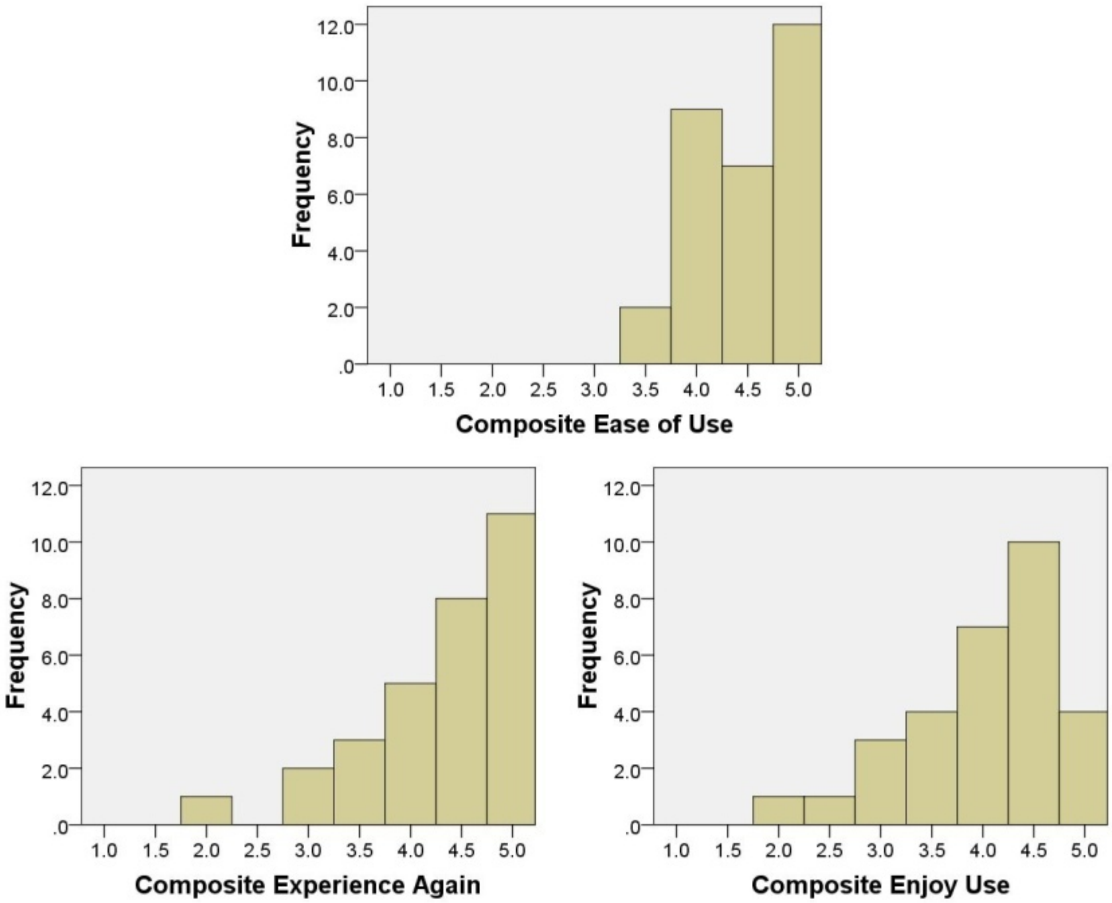


Figure 5. Survey statistics from Reading Glove post-interaction questionnaire

The charts in Figure 5 show the participant responses on the post-questionnaire, with “Strongly Disagree” coded as 1 and “Strongly Agree” as 5. Responses from the paired questions were combined to yield a composite measure. The second version of the question was subtracted from 6 (i.e. a score of “5” became a score of “1”) and then the responses were summed and divided by 2. The scores on “Ease of Use” (mean 4.483), “Enjoyment of Use” (mean 4.017) and “Experience Again” (mean 4.317) were consistently high enough that I feel safe in concluding that there were no serious usability issues that were affecting the way participants engaged with the system.

From the system logs, I recovered numerical information on a variety of characteristics of the experience (see Table 3). The first metric I looked at was the total number of lexia activated, which represents in a rough way how much of the story they heard. There were 20 total lexia, so fewer than 20 total activations meant that the participant did not hear the full story, while more than 20 indicated that they listened to some fragments multiple times. The mean number of lexia activated was 30, with the smallest number of activations being 11 and the most being 80. Next I looked at how long the participant spent with the system. The total running time of the story, listening to each lexia once, is 8 minutes and 50 seconds. On average, participants spent 17 minutes interacting with the system. This was considerably longer than in the second preliminary study, which had the same amount of story fragments but did not have the adaptive component. There, participants spent on average 11 minutes and 30 seconds interaction with the system, with a range from 7 minutes and 3 seconds to 12 minutes and 58 seconds. With this version, the shortest interaction time was 9 minutes, while the longest was 46. This suggests that the adaptive display drove a deeper and longer engagement with the story.

Table 3. Descriptive statistics from the Reading Glove study

	Minimum	**Maximum**	**Mean**	**SD**
Total Lexia Activated	11	80	30.4	14.4
Average Listens per Lexia	.55	4.00	1.54	.70
Minutes Spent Interacting	9	46	17.0	7.2

From the number of lexia activated and the total duration, it is clear there is a wide range in terms of how thoroughly the participants read the story. Some did not hear all the pieces even once, while others heard every piece multiple times. I was not able to identify any characteristic of the participants that significantly influenced how much time they spent with the system. The mean numbers for each metric suggest that the average experience was to listen to the story one and a half times before stopping.

4.4.1.2.1 Describing the Experience

After getting a handle on some of the quantitative aspects of the participants' experience, I turned to the qualitative data in the interviews to get a sense of how the participants articulated their experience. In the interviews, many participants discussed their experience of the system as moving through distinct stages of interacting with the system. Participant 24 summarized his strategy for interacting as follows:

> "[I] started out with random ones, and sometimes if I picked up a key word that I could relate to the objects on the table, I'd go for those even though I might not be prompted to do so. And then at one point, when I feel like I've heard most of the story, probably the whole story, I wasn't sure, I would just go around touching everything just to make sure I had covered

> all those aspects. And then try to piece things together in my head, to get a rough idea."

Overall, participants were able to be quite articulate about how they approached the system, suggesting that they had a strong self-awareness while interacting with the system that was able to come out when reflecting on their experiences in the interview. From the various reflective statements made following their interaction with the system, I have identified four phases that participants moved through in making sense of the Reading Glove: Orienting, Exploring, Re-Evaluating, and Wrapping-Up.

The typical progression that participants described was that they started off with an orientation phase, attempting to figure out how the system works and getting used to the interaction paradigm and what the recommender does. Participant 8 describes this initial stage: "I actually in the beginning was trying to figure out what are the parameters, what levels, like if I go back and forth and back and forth, how quickly will I get things repeating?" During this first period, they may not be paying attention to the story very closely, or they may not notice the animation of the recommended objects at first. Participant 4 notes: "Yeah, I think at the start I ignored [the recommender] because I didn't really notice until about 3 objects in." During the orientation phase, participants settle on an initial model for understanding how the system works, which frequently changes as interaction progresses.

Once they have settled into the system, participants have a period of exploratory interaction, where they follow either the recommendations appearing on the display or their own whims to select a series of objects and listen to the story. Some people may actively test different ways of interacting with the system. Participant 23 describes his method:

> "I was trying to figure out whether there were like different trees of the story triggered by the different pictures coming up and whether they were color coded or not, but that didn't seem to match up. I tried a couple [of] things. I tried doing the pictures that came up, but then I also tried to do the objects that were predominately mentioned in the story previously, to see if that could take me through. So if somebody mentioned the globe, that was mentioned, I'd go, oh, okay, this is the globe let's see where that goes. I was trying to order, I was actually trying to put it in linear order, I guess that's kind of what I started to do. I wanted to get the beginning somehow, so I felt very satisfied when I got to the beginning, I think it was the rose. Because in the beginning I thought I was in the middle of it and I gotta get out of it."

Many people during this stage will try and interact with each of the objects at least once, and may even try and physically order them sequentially before realizing that this is a challenging task due to the multiple story fragments.

At some point during this period, the participants may return to the same object a second time, and realize that it has another story fragment. Although the training and the instructions at the start of interaction indicate that this is the case, many people are surprised by this fact and this causes them to re-evaluate their understanding of the system. Participant 1 said:

> "So, when I went back to some for the second time, it was different and it didn't really…I went to most of them once before I went to any of them a second time, so I'd forgotten the training that there was a second, there was a different clip, and that kind of…it was a little bit frustrating because I thought that, at first I thought that "Oh, I'll just go back through these and I'll figure out exactly what the story is", but the story is like twice as long as I thought. So then you have to work more to figure out what the story is, but it was still really entertaining."

Some participants experienced a second surprising shift in their system understanding when they encountered a repeated segment for the first time as they loop back to the first lexia on each object, taking them back to the beginning of the story. Participant 12 felt this was a very powerful moment:

> "So all of a sudden I hit another point and it said something I'd already heard before, and then I thought "woah, woah". And this is where it gets to the part where maybe it's a critique, whereas before it was such a rich experience, now I thought "so, I can go back to details I've experienced before, but I have no control over whether I can go back or not, whether I'm going forward. So I have no idea if I pick up the camera or I pick up the coffee grinder, and I have the option to pick up any of these things, whether it's going to advance the plot or inform some question I have about something. And at that point I felt powerless within the context of the story. Now that could be very effective, if used well, if your intention there is to create a sense of powerlessness in the reader, to some narrative or some thematic end, I think it could be awesome, but I'm not…It's the sort of thing, that would be the central question I have in experiencing it a second time."

This notion of control versus choice and the idea of powerlessness is returned to below**.** From this point, participants gradually shift into a more directed interaction as they attempt to uncover specific information, return to previously heard items, or in some other way confirm that they have heard everything or understand it all correctly. Their understanding of how the system works typically solidifies during this time period.

Finally, many people enter a wrapping up stage where they jump around from object to object, interrupting segments frequently as they look for specific pieces. Participant 3 recounts that

> "towards the end of the story, where there were some scenes that were set in the apartment and some scenes that were set in the bar, after the bar thing had kind of come to a conclusion, I wanted to get more in his home, and so I was choosing, like, the globe or the vase, things that I thought would have a connection to his house as opposed to the bar."

Other final phases include replaying previously-heard pieces until the participants were satisfied with their story comprehension or until they believed they had found everything. Participant 24 describes this stage: "When I started hearing the same stories, I tried to go round touching everything to make sure that I've initiated or triggered all the objects, to get all the stories I want. And then when I realized I've heard all of them, I thought that's probably it." Some people became more experimental in their interactions at the end, with participant 26 describing his more exploratory actions as follows:

> "Initially, yes, [I followed the recommender] but then towards the end I just starting getting spastic and wanted to see what would happen with the system if I did different things. So I chose…some of them I chose random images, other times I chose the object that was nearest to one of the objects lit up, versus its actual representative physical object. Sometimes I just chose cross paths, and again I just chose the images that…I tried to go back in my memory to remember what triggered what to try and recall a sequence again. At the end I just tried to break my pattern, to see if I was doing things differently and in that sense I did end up….the reward for that was I got one new piece of information, which was I think one of the very very initial parts of the story, I think maybe even the first part of the story. By accident, so I don't even know how I got it. It was just the random sequence that I had chosen that led me there."

The lack of a distinct end point was frustrating or confusing to some people, who wanted a clearer indication that they were finished.

While not all participants followed this framework precisely, the stage progression of Orienting -> Exploring -> Re-Evaluating -> Wrapping Up describes commonly shared elements of the experience of the Reading Glove. Developing a detailed understanding of the stages people move through in grappling with new technology could lead to being able to detect what stage a user is in and facilitate their movement to the next stage. Although the adaptive effects of this system were focused elsewhere, the use of adaptivity in this detection and response would make sense. The progression also gives some insight into the shifting perceptions of the adaptive components over the course of interacting with the system.

4.4.1.2.2 Experiencing Adaptivity

In this section, I delve in more detail into how participants discussed their experience with the adaptive components in the post-interaction interviews. At the start of interacting with the system, participants were given minimal information on how to understand the recommender system, in order to provoke their own interpretations. They were told that the tabletop display “can help guide you through the story”, but given no details about how that guidance was generated. One of the most common ways participants described the recommender was as a system that gave “hints” or “clues”, as when participant 3 said: "And you get some hints on the map of which objects would be useful to try next....The ones that got bigger were sort of your clues for, if you touch one of these objects, something useful will happen." A couple participants also referred to the recommender as providing “links”, with participant 29 saying "Well, I think it's supposed to guide me to the possible link between each item.” Similarly, participant 7 said identified the recommender images as being "kind of like wayfinding or navigational devices" and participant 12 that "I only ever really took that to mean, to be a guideline, like you should probably select one of these three. I know you can pick up whatever you want, but probably pick up one these there." Four participants had a negative or dismissive take on the recommender, saying that sometimes they thought it was simply a “trick” or intended to confuse or distract them.

Discussion of the tabletop and the recommendation system often did not come up in the interviews until participants were directly queried about it; most people chose to talk about the objects and the story more than the tabletop and the recommendations. Participants were often hesitant to make guesses about how the recommender worked, and gave fairly vague and hedged responses when asked directly. The most common guess put forth was that the recommender was responding in some way to the last object touched, but exactly what that response consisted up was unspecified, as when participant 2 suggested that “it was probably responding to what was the last object that I touched before I touched the new one." Participant 22 got a bit more specific, saying: "My guess is that the one that I used, so if I picked up the coffee grinder, the one that would be the best to hear illuminated itself or got bigger. Something that would be relatable got bigger on the screen, to give me a kind of path, but I didn't have to follow it, which was nice." When pressed to generate more specific guesses about what determined the objects that were recommended, most participants guessed that it was based on the linear order of the story, with the recommended objects being those that were immediately before or after the last object selected. Participant 27 said "I think they were trying to relate in terms of the order. So you pick up one, and these are three things that would happen in relation to it or after it." Two participants ventured that the system might use more information than just what they picked up last, speculating that the recommender might be looking at a sequence of items that they had selected. Participant 20 said "I was thinking maybe it is depending on the sequence of the object that you pick up, it's capturing my patterns to figure out whether I understand the story behind the first action or not. Something like that."

Participants had a wide range of strategies when it came to following the recommender. Most participants followed it at least some of the time. Participant 21 described his strategy as "I think it was about a third of the time I chose one of the large ones. Usually I chose one of the larger ones when I wasn't sure where to go next." There were a few people who decided to ignore the recommender, such as participant 8:

> "It looked like there were clues as to where to go next. By and large I ignored them. I thought that the image behind was very interesting. I thought it was kind of odd that there were icons of the objects that I…There are objects and then there's these icons of these objects, and then the icons sort of grow and what not, and I'm going "I've already got the object in my hand"."

There were also a few participants who stuck to the recommender very closely. Participant 18 said "And I chose based on [the recommender], and I didn't veer from it, because I felt like I would confuse myself. I didn't want to confuse myself already, so I just chose from whatever it suggested." The most common strategy was a combination approach that involved following the recommender at first and later branching off according to personal interest. Participant 22 said:

> "I thought that the pictures were meant to tell me what I should probably pick up next, so I started there. The first time I picked up an object, I listened to it, and then I saw the screens enlarge for various objects, and then I would probably go to that object next. When I gave that up, it was because my interest was piqued in other objects, and I really wanted to touch that rose and I never kept seeing it come up. So I said 'waah, I'm not going to follow this anymore, I'm going to go and pick up whatever I want'."

When not following the recommender, the reasons given were typically that the person was more interested in a specific object or trying to track down a specific piece of the story. Participant 24 described his variable strategy:

> "I changed a couple times. Started out with random ones, and sometimes if I picked up a key word that I could relate to the objects on the table, I'd go for those even though I might not be prompted to do so. And then at one point, when I feel like I've heard most of the story, probably the whole story, I wasn't sure, I would just go around touching everything just to make sure I had covered all those aspects. And then try to piece things together in my head, to get a rough idea."

When following the recommender, most people let intuition or interest select between the three recommendations, often guided by story content. Participant 16 put it thus:

> "For about the first half, I picked objects up in sequence according to what was highlighted, and there were several options, but I would sort of pick based on what sort of fit the narrative to my mind. Like, if the narrator alluded to a camera, and the camera was one of the highlighted options, I might do that one."

From the system logs, I calculated how frequently participants followed the recommender by selecting one of the highlighting objects as their next object. On average, they picked an object highlighted by the recommender 68.8% of the time, ranging from a low of 19% to a high of 98%. Adding the tabletop and the adaptive recommendation system was intended to help guide the participants through the story, but the result of the addition was not straightforward. The role of the tabletop was interpreted in a much more variable way than the glove and the objects, and caused participants to become more aware of the overlapping physical and digital elements of the system. The doubling of representations between the physical and virtual worlds caused some confusion, with participant 8 saying "I thought that the image behind was very interesting…the double representation of the object I thought was kind of interesting. Interesting is the wrong word. Kind of odd." At the start of each session, the objects were placed on the tabletop in a position that was across from their photo on the tabletop display. This was done to make it easy to always set up the table the same way, while not making it seem like the objects should not be moved from their starting point, as might be the case if they were placed right next to their picture. Participant 26 noted this arrangement and said:

> "I noticed immediately that there was an inversion of all the objects on the opposite side of the table from their pictures, so part of me was tempted to rearrange the objects and put them where they were supposed to be. And also at the same time I was wondering “Well, if the pictures lighting up and it’s saying the thing on the opposite side, what happens if I choose the one that’s right next to the picture”, and towards the end I was just starting to experiment to see what caused different things. "

Participant 7 described her experience of the tabletop quite poetically, saying:

> "And I thought that that, perhaps, was the….which means that my sense of feeling transfers into being, and I’m describing that as kind of bleeding out, that I’m feeling and being...There’s like this creative leap, where you can just sort of…like, I wanted to see, to be able to move the images of the objects on the screen and I also wanted to see physical movement through the screen itself. So, with each, as I traveled into the story I wanted to see rather than a static map, I wanted to see indications of where I was, on that map...[It's like] this window into another world. So in a way it’s kind of like a bridging form, which helps me kind of negotiate my way in that virtual space. So it’s a very good, strong, physical intermediary to a virtual space."

The fact that the tabletop was simply a display surface clearly confounded people’s expectations that a digital tabletop would provide additional interaction and information on demand. The design goal of simple and direct interaction via the glove seems to have made the tabletop appear complicated and cumbersome in comparison.

4.4.1.2.3 Differences across Conditions

So far, I have not broken the analysis down according to what condition the participants were placed in, i.e. whether they used the random, story content, or user model recommender. For the most part, there was no discernable difference in the way people in the different conditions talked about the purpose of the recommender or how they thought it worked. However, there were two types of comments made by participants that do correlate with their condition, and some statistical results related to condition as well.

Seven people said that they thought some of the recommendations they saw were nonsensical or appeared to be random. Of these seven, five of them were in the random condition, one was in the user model condition and one was in the story content condition. Put another way, 50% of the participants in the random condition expressed some doubt over how sensible the recommendations where, whereas only 10% of the participants in one of the two intelligent conditions expressed the same feelings. Participant 1, in the random condition, said:

> "It seems like sometimes it didn't really makes sense, like, the recommendations, I would choose one, but that didn't really have much to do with the clip I just listened to, because there was like 2 or 3 clips with each object, and sometimes it seemed like it was the wrong one or I'd heard another clip from that object that would have followed better and I wanted to hear that one again because I forgot it."

Participants tended to feel the recommendations did not make sense when they jumped abruptly in time or space in the narrative, i.e. when the next clip did not seem to follow from the previously heard one. Five people mentioned having a poor experience when they chose not to select one of the recommended objects. All five of these people were in one of the two intelligent conditions, with two in the story content condition and three in the user model condition. They described the resulting sequence as confusing, "out of order", going "sideways" or being broken up. Participant 26 said "The ones that got bigger were sort of your clues for, if you touch one of these objects, something useful will happen. There were one or two times I said "to hell with your suggestion", and it wasn't particularly rewarding." These experiences convinced them to return to following the recommender's advice.

Above I discussed the amount of time the recommender was followed, and Figure 6 breaks this statistic down further by condition. There was no statistical significance found in the differing distributions of recommendation following percentages across the three conditions. However, simple observation of the charts shows that the random condition is distributed more widely across the percentages, while the numbers of the intelligent conditions, especially in the user model condition, cluster near the higher end of the scale. This suggests that in the intelligent conditions, participants trusted and thus followed the recommendation system more frequently. Further studies would be needed to prove this result more conclusively, but the data is suggestive nonetheless.

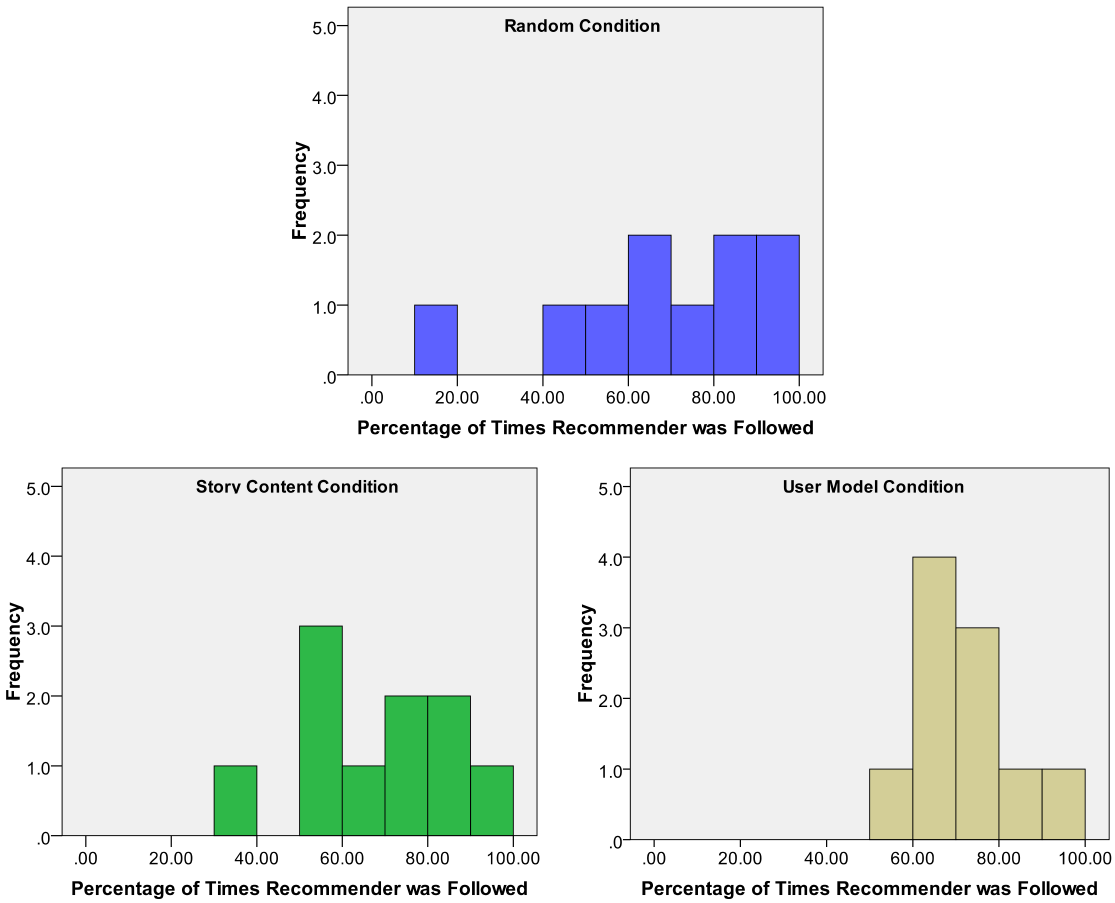


Figure 6. Percentage of times recommendations were followed, by condition

In the user model condition, there is a special mode that could be activated if the participant selected the same type of recommendation (theme, importance, position) repeatedly. In this mode, the object recommended by the frequently selected recommendation type would show up before the other two recommended objects. The user modeling module was actively pushing recommendations forward an average of 42% of the time for the participants in the user model condition. Everyone in the user model condition activated the component for at least a handful of times, even though not all of them reported being aware of the single recommendation mode when asked about it in the interviews.

I also looked for patterns in participant behaviour that indicated an unconscious reaction to the nature of the intelligence underlying the system, even if they could not articulate that understanding fully when questioned. I began by examining descriptive statistics based on the data in the system logs, which included elements like how many distinct lexia each person listened to, how many times they followed a recommendation, and how much overall time they spent interacting with the system. One thing that stood out early on was that one of the 30 cases was an outlier in almost every metric collected. Because this participant's numbers were so far outside the cluster of everyone else, I have chosen to discard that data in the following statistical analysis rather than allow it to skew the results. It seems clear that this person interacted with the system in a very different way than the rest of the participants. With a larger sample, it might be possible to identify whether this represents a particular subset of the population who consistently responds in this particular way, but in the absence of more data I cannot tell what is going on.

In examining the descriptive statistics and graphs of the data collected, I identified two key behavioral factors where the participants in the random condition appeared to be on the low end of the scale compared to the participants in the two intelligent conditions (see Figure 7). These were "Average Listens per Lexia" and "Total Lexia Activated", measures that are related to each other. Both of these measures give an indication of how much of the story was listened to. Since there were 20 lexia, participants who listened to fewer than 20 total lexia did not hear everything. Average listens gives a similar indication of the saturation of the reading, with a score of 1 indicating that they listened to each lexia once, higher numbers showing that they listened to some of the lexia repeatedly, and lower numbers indicating that they did not hear every piece of the story.

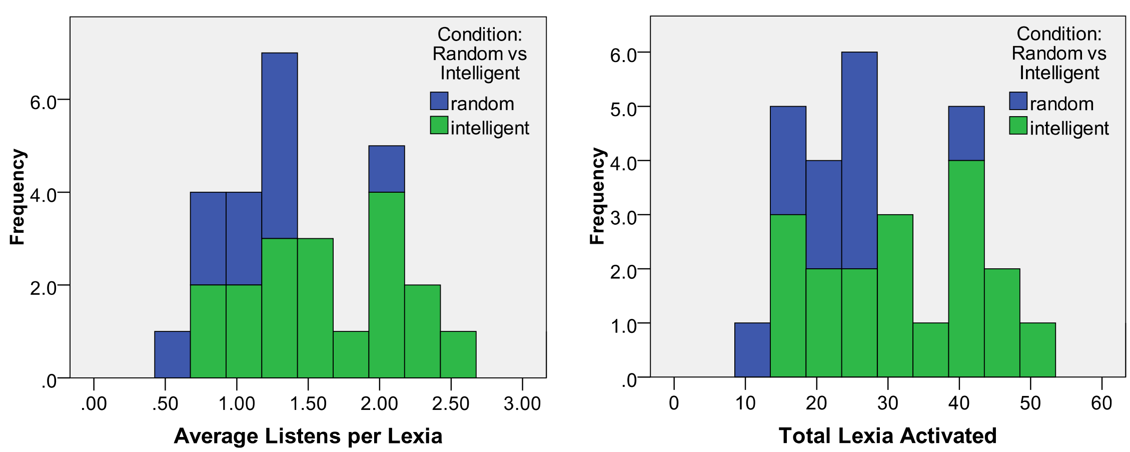


Figure 7. Frequency distributions for two behavioural measures separated by condition (random = blue, intelligent = green)

I ran an ANOVA on these two factors to see if the apparent correlation between condition and behaviour was significant. There was a significant effect of condition on the number of lexia interacted with: $F(1, 27) = 4.736$, $p<.05$, $w = .33$ as well as a significant effect of condition on average number of listens per lexia, $F(1, 27) = 5.838$, $p<.05$, $w = .38$. What is particularly interesting about this result is that I also ran an ANOVA on amount of time spent with the system, and failed to find a significant correlation between time spent and condition. So it was not simply that the interactors in the intelligent conditions spent more time with the system, but rather that they listened to more lexia repeatedly within the time that they spent. This points to a deeper and more dedicated engagement with the system that is driven by the adaptivity, even if awareness of that adaptivity or the quality of engagement is not reflected in the survey questionnaires or most of the interview data.

4.4.1.3 Proposition 1 Summary

In examining the designers' intentions versus the participants' experience, the following key elements are seen:

Designers

- The designers included adaptivity to support story navigation and narrative understanding
- The designers aimed for simple, direct interaction with the story via the tangible interface
- Different adaptive components were developed to see how subtle differences affect experience

Participants

- Participants found the system basically usable and enjoyable
- They engaged in active interrogation of how system worked, both in terms of story delivery and the recommendation system
- They moved through observable stages: Orienting -> Exploring -> Re-Evaluating -> Wrapping Up
- They displayed a subtle awareness of the different adaptive components in terms of how much sense the recommendations made and how much they trusted the system

4.4.2 Proposition 2: Interaction with Tangibility & Ubiquity

Proposition 2 states that: Designers believe that adaptive components can increase the ease of use or enhance learning or other experiential elements of ubiquitous systems, but in fact the adaptive components are more likely to add hidden complications. In this section, I look at how the tangible glove and objects interacted with the adaptive components of the system. First I use design documentation, published papers, and my personal insight to explore what the designers' goals were with regard to interweaving the tangible and adaptive aspects. Then I turn to the interview and observational data from the user study to understand how the participants experienced the tangible and adaptive elements.

4.4.2.1 Designers: Combining Tangibility and Adaptivity

One of the starting inspirations for the Reading Glove was the idea of *psychometry* or object reading, the fictional psychic power to draw out memories and experiences from an inanimate object. The goal from the start was to explore how the metaphor of psychometry could be used to tell a story using tangible and wearable technology. The use of "paranormal phenomena" as inspiration for tangible interface design has been explored previously and can help users make sense of novel interaction paradigms (Svanaes and Verplank, 2000).

The interaction with the objects was designed to be as direct as possible, with three primary criteria taken into consideration when designing the initial glove-based interaction (Tanenbaum et al., 2010a):

1. Interactors needed to be free to move around unencumbered by cables or other technology
2. Interactors need to be able to use both of their hands freely, without the need for additional overt interactive "tools" or other interface devices.
3. The interaction needs to encourage participants to physically handle the objects in the narrative, without interfering with the experience of the objects.

The first few versions of the system were aimed at nailing down the system interaction and the narrative, with the intelligent components being added once the core interaction was established.

To evoke the feeling of psychometry, the glove was constructed to give the interactor the ability to draw audio story fragments out of objects by picking them up and holding them. Early sketches of the glove considered adding a button or rotational element to the glove, which would allow users to move through different clips of the story associated with each object. In the end, a simpler interaction method was determined to fit the design goals best. The basic interaction with the objects was to be as direct as possible: pick up the object, hear the story.

4.4.2.2 Participants: Grappling with Tangibility and Adaptivity

Analyzing the video data gives a slightly different perspective on how people experienced the Reading Glove by looking at how they engaged with the physical objects in the moment, rather than how they conceptualized the system verbally afterwards. In this section, I identify five different qualities of engagement with the wearable and tangible interface, drawing on both the video data and the interviews. These qualities are not stages like the sequence described in section 4.4.1.2.1; while most participants showed multiple different qualities of engagement throughout the interaction, not everyone went through the same sequence or covered all of them.

In the video logs, some of the participants were observed to be deeply engaged with the objects, possibly to the detriment of their story understanding. They moved any part on the objects that could be moved and examined them thoroughly, exploring the heft, the texture, and the mechanics of the objects. Sometimes participants would make use of the object, such as wearing the hat, clicking the telegraph key, or rotating the handle on the coffee grinder. They appeared to take delight in handling the objects and exploring them via touch and sight. Sometimes this physical engagement with the objects proved to be a distraction, with people failing to pay attention to the story because they were engrossed in the objects. Participant 28 sums it up:

> "I think there's a lot of…I've was trying to experiencing the story through my haptic senses and it's interesting. I wasn't quite sure what that box was, so I was tinkering around with it and even with the coffee grinder, I could actually manipulate it, so that adds to it. But at times I was slightly overwhelmed because I'm partly listening to the story but I'm also playing with these objects in front of me."

Nevertheless, many people expressed a basic pleasure in just holding the objects and manipulating them. Participant 4 describes it in terms of immersion: "Much more immersive than probably anything except for books that I really really love, and that I can immerse myself in. Because when I was handling those objects and listening to a story and looking at the overhead view of Algiers, I don't recall sensing anything else around me." Other participants said that it was "neat", "cool" and "fun", but participant 3 summed up the hard-to-articulate nature of this physical pleasure thus: "There's something nice about the collection of old time objects. I'm not entirely able to say what it is, but there's something tangible and connectible." Participant 22 said:

> "I liked the way the tags hung off from different places, because I would have to find the tag and it also informs how to engage with the object. So, that object's really heavy, so you have to sort of go around, but that's cool, I think that's really interesting. They're all light enough to pick up, but they're sort of…some of them have some weight to them as well, so there's a variation. And they're just interesting objects to engage with. You touch them, and you hear the corresponding story, it's pretty cool….It's interactive, in a very analog way. And just not, but it feels analog even though it's not. It feels nice. There's a tactile quality to it, almost reminds me of play, like when you're a child and you're playing with stuffed animals or something. You play with them and touch them and they have little narratives, you make the narratives. So it's kind of like playing with toys for adults."

The ability to interact with actual, historic objects was, in general, one of the most positively received aspects of interacting with the Reading Glove. The tactile qualities of the objects, as well as their sense of historical heft, made them engaging and attractive pieces to manipulate. However, the highly engaged interaction with the objects was not sustainable over the duration of the entire session with the system. Participants who explored and played with the objects on the first activation would typically not continue that exploration when returning to the object a second time. Their general approach was still playful, but more oriented towards story understanding.

A second way of interacting with the objects was a more functional, pragmatic approach. In the video logs, some participants engaged with the objects in a much more minimal manner. They might pick up an object and hold idly for extended periods of time, or move them around on the table occasionally, but they did not spend a lot of time actually looking at them or manipulating their parts. While listening to an audio clip, they might give the handle of the coffee grinder a spin, or turn the globe, but it appeared to be more of a fidgeting behaviour rather than an engagement with the object itself. Many participants with this level of engagement appeared to be hesitant when touching the objects, as if afraid of breaking them.

Several people noted with some disappointment that the unique movements and affordances of the objects, such as turning the coffee grinder crank or tapping the telegraph key were "non-functional" in that they did not trigger a system response. Participant 21 said:

> "I don't know, there's something about having something physical to play with and move around, even if the movement of it doesn't seem to do anything. Makes it interesting. I liked that, but I wished there were more things I could do with the objects, that there was more…that moving them, that turning them, that playing with them actually changed the interactivity rather than just being a trigger."

Their moveable attributes were appreciated nonetheless. Participant 16 noted:

> "I thought it was cool I could feel the heft of them, look around them and I felt sort of…I was able to go into the world enough that I was thinking of the objects in terms of their use in the story. You know, I opened the beer bottle to smell it. I tried on the glasses, I opened the coffee grinder, I spun the globe. It also sort of just gave me something to do while I was listening, in a positive way, not like bored, but just kind of getting the texture of the world. It definitely added something."

Several people attempted to move the objects around to keep track of what they had listened to or what order they were supposed to go in. Participant 11 said: "I liked that I could move them around and play them in order. Even though it didn't help in the end, the objects that I thought were "done", I would put them away and the other ones that I wasn't sure about, I would still keep them close to me." It was not ultimately possible to put the objects in the "correct" order, as each object had two story pieces on it and the object order was not the same in the first half and second half of the story. The people who attempted to order the objects physically eventually realized this fact and gave up trying.

Finally, there was a small group of participants who seemed completely unengaged with the objects, to the point where they seemed to avoid touching or holding the objects as much as possible. In the video logs, participants in this group did not move objects from their original position or spend any time looking at them in detail or manipulating them. Sometimes they would go out of their way to maneuver the glove close to the object tag without having to touch or move the object at all.

In the interviews, four of the 30 participants said that they found the objects unengaging and that they would have rather just interacted with a digital environment, i.e. that the objects themselves did not add anything. Participant 30, in response to the question "How did being able to touch the objects affect your experience?" responded simply: "Not much", and participant 28 similarly said "Honestly, I would have liked to just interact with the tabletop and not have a physical object. I think it's…it creates an extra interface." These participants seemed to be more goal-oriented than the others, focused on hearing the whole story and putting it together rather than seeing the experience of handling the objects and evoking the story as part of the pleasure of the activity. Several participants also noted that there was a fade point for the engagement with the physical nature of the objects. While they might be really into examining and exploring the physicality of the objects at the beginning of the interaction, by the end they had figured out the quickest, easiest way to trigger them and did not engage with their tactile properties anymore. Participant 3 describes this process: “But I think that might have been a short-lived novelty, because at first it was like you pick it up and you feel the heft and the weight and you examine the object, and then by the end it’s how can I reach my hand to hit the RFID without actually having to touch the object?... It was neat to pick them up once or twice, but after that it was just hit...hit...hit.” This observation is born out in the videos of participants interacting with the objects. The start of each session contains a great deal of variety in terms of how people engage with the objects, as described above. By the end of the interaction, though, almost everyone’s interaction looks the same: there is minimal holding and examining of the objects. They are triggered while still sitting on the table, or picked up to access the tag and then set down again quickly. Since the system does not require unique or complicated interactions with the objects and exploratory behaviour is not explicitly rewarded by the system, the novelty effect fades and the use of the glove when handling of the objects is reduced to a simple user interface action of “clicking” on the tag.

The tangible nature of the Reading Glove’s interface had a clear impact on the expectations people had about how the system would work, which they then tested throughout their interactions. Many of the participants assumed that 1) the manipulation of unique elements of the objects would produce a unique system response as opposed to the generic “click” interaction that was actually implemented, and 2) because the objects were capable of being arranged in spatial relationships to each other, that physically putting them in order was possible. While the physical nature of the objects was seen as a positive, attractive attribute for many of the participants, the physicality also gave rise to expectations which, when proved to be incorrect, contributed to a dropping off of deep engagement with the objects.

4.4.2.3 Proposition 2 Summary

In examining the designer and participant perspectives on tangibility and adaptivity, the following key elements are seen:

Designers

- The designers used the metaphor of "psychometry" or object reading to design the interaction
- The interaction was intended to be as simple and direct as possible.

Participants

- Some participants experienced deep engagement with the objects, to the point of distraction
- Others wanted more functional interactions with the objects
- Some participants had little interest in engaging physically with the objects

4.4.3 Proposition 3: The Effect of Adaptivity

The final proposition under consideration is: In tangible or ubiquitous systems that utilize intelligent techniques to provide adaptive system responses, the designer's intended adaptive effect differs significantly from the actual experience of the adaptive system by the users. To address this proposition, I draw on the analysis already completed in the sections above, and add in some additional questionnaire and interview data.

4.4.3.1 Designers: Goals of the Adaptivity

In section 4.1.1.1 above I discussed the intended benefit of the adaptive components, which was to assist the reader in navigating the non-linear story.

4.4.3.2 Participants: Actual Adaptive Effect

With proposition 1, I showed that the intended benefit of the adaptive components, to assist in navigating the non-linear story, was not necessarily experienced by the participants, although they did show some awareness of the adaptive component. Here I explore in more detail where the participants thought they might be seeing adaptive effects, if not in the intended aspect of the experience.

4.4.3.2.1 Ascription of Adaptivity

In addition to the ease of use and enjoyment of use questions described above, I also asked in the post-interaction survey whether or not participants felt like their actions changed the story.

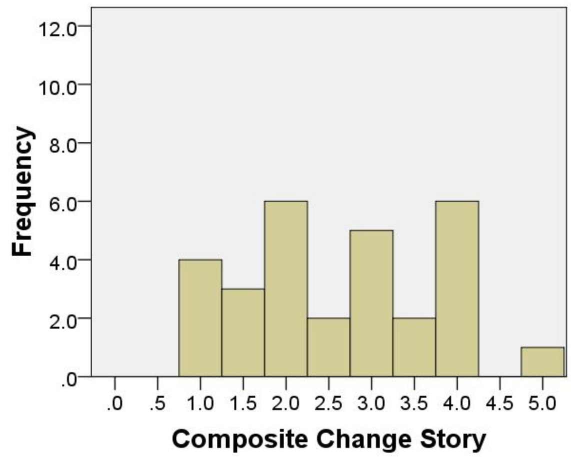


Figure 8. Survey response on whether or not interactors felt they changed the story

Unlike the other survey questions, the response to this question was spread across the chart, rather than clustered on the right (see Figure 8). The biggest stumbling point for most people was the non-linear nature of the story and figuring out how to reassemble the narrative. A number of people believed there was some sort of branching going on, so that choices they made early on affected the paths that the story took or the ways in which the plot was resolved. Participant 3 discusses the possibilities he entertained in terms of how the story delivery worked:

> "it felt like in some cases, the object was sort of selecting a camera, in the sense of this narrative is pre-determined, and it's just a question of which frame do I hear it from. And other times, it seems like this is a branching narrative, and I can choose which branch I want....I was never entirely sure how much the narrative was all pre-determined, and how much was branching.... I remember at one point I picked up the hat, and it said that he picked up the hat to try and blend in with the bourgeois in Algiers, and I think that might have been when he went to the bar. And so my suspicion is, instead of picking up the hat, if I had just picked up the beer bottle, that he just would have gone to the bar without putting on the hat. So a little bit of branching, but not really a lot."

Participant 14 said:

> "And as you trigger a portion of the story, it gives you; sort of opens up other branches of the story with different objects. It also cues you on the table what kind of objects might continue a new portion of the story. So if you pick up one of those objects, the assumption is that you will somehow continue….well, my assumption was that you will continue that sort of story strain. If you pick up another object, it will break off into something a little different or separate from that main story, or that story strain you had already started. And as you trigger different objects, it opens up other channels. It's sort of like a broken narrative that you piece together yourself."

Others seemed to think that the story was fixed, but were unsure how many clips were on each object or thought the associations between object and story changed throughout the interaction, with the system shuffling the clips around to different objects. Participant 19 describes her guesses:

> "For me, whenever I pick an object, and I press it, then it tells a story. Also, I see there are several objects on the screen, just became bigger, but I don't know what the relationship, whether it will make difference if I picked one of these objects on the screen or I just picked another object. So I didn't figure that out, what's the difference. Also, I think each time I select an object, it will tell different story. But I noticed that the pieces actually repeats, but I didn't remember whether it actually repeats from the same…I think it should be it repeats from the same object, because each object tells a story related to this object, right? So, yeah, I don't know how it works, it just repeats sequentially or randomly, I didn't figure that out."

A handful of people seemed to realize that each object was associated with only 2 clips, that those clips could be cycled through systematically, and that the story content was fixed and did not change based on participant choices. Participant 6 was one of the participants who had an accurate understanding:

> "I think there is only one story, right? So the only thing I can do using this stuff is choosing the sequence, which plots first appears or appears in some time. But I can't really change the story, so the choice is limited, I think....For the first half, I did [think the story changed], but for the second half I realized that there is only one story."

Half of the participants discussed experiencing some variety of cognitive load or difficulty dealing with the non-linear and fragmentary nature of the story. Among the things that were mentioned as challenging were: 1) The non-chronological order requires remembering more and holding the story in mind and rearranging it to make sense, 2) They encountered sequences of fragments that did not follow from each other or transition well, 3) They could not skip back and review previously heard material quickly,

4) There was a period of getting oriented to how the system worked and picking up on the setting and starting context of the story before they could really focus on the story content, 5) The duration of the reading was problematic, as participants felt they could not do it for too long because it was wearying and because there was a set time allotted for the study, 6) They were trying to keep track of which objects had been interacted with already and which had not. This increase in cognition was sometimes listed as a positive result of the experience, with participants claiming it increasing immersion by forcing one really pay attention and to make connections between the story fragments.

Several people talked about not trusting themselves or their interpretations of the story because of the difficulty of piecing together the non-linear story. Participant 10 said "I don’t know if I know everything. So that’s hard to judge, if you know everything." Participants worried that they had not uncovered all the story fragments, or that they had failed to remember and piece it together correctly. They were unsure whether they did it "right", as with participant 17 who said: "I was probably navigating the story in a different sort of way than was intended". Participants 26's opening response to the prompt to retell the story captures the flavor of the hedging that many participants engaged in: "Okay, to the best of my knowledge. There is...and again I don't know if I missed it or failed to find the spot where it was said, but the character that you're following is narrating his own experience. I don't remember a name if there was one." This self-doubt led to a complex relationship with the concepts of “control” and “choice” with regard to the system.

Two thirds of participants talked about the idea of choice. Choose Your Own Adventure stories were frequently mentioned as an experience that was similar to the Reading Glove, but the notion of choice was deeper and more complex than that. When asked to describe the system, the responses often centered on the key role of choice in the interaction. Participant 3 said "I would say that there’s a story that’s happening and depending on which objects you choose to touch, you hear different parts of the story." Participant 10 phrased it as “basically it tells you a story and you can have an influence on how the story is told to you with these objects." When asked how they selected which object to pick up next, the role of the participant as choice-maker came to the fore, and it was here that the effect of the adaptive components were intended to have the greatest effect. Participant 28 described this as "Whereas in the beginning I’m just testing things around, there wasn’t too much intention in terms of which objects I’m picking up, whereas later I'm actually making meaningful choices." What choice meant to participants varied. Some participants figured out that the story was static and that the fragments heard flipped back and forth. For them, choice was more navigational and less exploratory. Participant 22 said "I would say it's more like a book than a game, I guess because I didn't feel like I had an effect on the story, and to me a game is something that you have a little more effect over how the story is played out. I guess I have effect over what I hear, but that's not quite the same to me." Participant 14 phrased it as: "Well, being able to guide the story in some ways made it much more personal, because it was much more “me” interacting with the objects and “I” controlling how the story flows."

As seen previously, most participants were uncertain how the story delivery worked and thought their choices might have an effect on the story content. For them, choice of objects was therefore more loaded than the people who viewed it more as a navigational method through a fixed and determinate set of options. Participant 12 wondered:

> "Is it just different objects meaning I'm going to do the same thing with them, or are these different objects meaning I'm going to make different choices, I don't know....I can go back to details I've experienced before, but I have no control over whether I can go back or not, whether I'm going forward. So I have no idea if I pick up the camera or I pick up the coffee grinder, and I have the option to pick up any of these things, whether it's going to advance the plot or inform some question I have about something. And at that point I felt powerless within the context of the story."

Similarly, participant 3 entertained several different notions of what his choices meant within the system:

> "I was never entirely sure how much agency I had. It seems like for a few of the branches, when you select the object, then the object would become very intricate to the narrative. I was like, “well maybe I chose to use this” but other times, an object would be more about a sort of general theme or…Not just that, it felt like in some cases, the object was sort of selecting a camera, in the sense of this narrative is pre-determined, and it's just a question of which frame do I hear it from. And other times, it seems like this is a branching narrative, and I can choose which branch I want."

A final element related to the notion of control and choice is the idea of creation, or “making the story yourself”. Several participants described their interaction with the system in terms of how their involvement with the objects was what made the story "go".

Participant 7 said "I have to move the story through my own physical movement, and that's really cool," while participant 8 said "it's very much a self-directed story". Even when people were certain the story did not change, so their actions had no consequences in terms of how the plot unfolded, there was a sense that their presence within the system was providing some sort of motive force. Participant 7 said:

> "I think that it's like the difference between an automatic car and a stick shift car. My consciousness has to change, to drive a stick shift car, you have to be aware of the where you are, how fast you have to go, to move the gears, and if you don't, the car doesn't run. You can't just put the car in automatic and go. And so I find the same thing with this interactive story mechanism that you've created, because I have to drive, I have to move the story through my own physical movement, and that's really cool."

Other phrases used to describe the experience included "you can have an influence on how the story is told to you with these objects", "I had to collect all the information to reform the story" or "By selecting certain objects first I might miss out what happened earlier, so I need to reconstruct the story again." The act of assembling or reassembling the story is seen as a kind of creative act.

Interestingly, participant 18 used the phrase *make the story yourself* in two different contexts, and one time it was a negation. When asked to describe the system, she said: "I would say it has different objects that you would interact with that convey the essential details of the story, and it's not a linear story, it's a….what's the opposite of linear…it's non-linear, so you have to decide, you essentially make the story yourself." Later, when asked whether the story changed based on her actions, she replied "I don't think I did. I think it was dictated for me, based on the fact that there is a linear story underneath it, and I had to figure out where that was, so it wasn't like I could make that story myself, or have the agent end up in a different situation."

4.4.3.2.2 Controlling the System

Most of the participants in the Reading Glove study talked about control explicitly or implicitly. Several people complained about the lack of control and noted that they would have liked to be able to easily and quickly revisit previously heard material. Other participants noted that there was a lack of direct control over the system in this manner, but did not see this as a strictly negative characteristic; it contributed to the ability to explore the system and discover or uncover the story there.

Others claimed that they did feel a sense of control, often connected to the notion of choice, of being able to "move at my own pace or in my own way" (Participant 2) or "have an influence on how the story is told to you with these objects" (Participant 10). Although they did not know what the results of their choices would be (i.e. what fragment they would hear and how it would connect to the previous ones), the fact that they got to choose gave them a feeling of control. This also came out in response to the question of how the Reading Glove compares to a book, with the Reading Glove being described as a more active engagement with the story because of ability to make choices and decide where to go next. Participant 6 talked of being able to "control the flow of the story", while participant 7 remarked "I had no control over where it was all going".

In one of the more intriguing quotes, participant 30 describes the Reading Glove as an:

> “Interactive story based on objects that you can touch and discover. Again, but you don’t have control. If I want to go back or listen back, I want to go back to the chapter where I missed something, there is no definite way. In the end, because it is short story, the third time you touched the same object, obviously you got the first version.”

That is, just after asserting that there was no way to “control” the system, he affirms that he knows exactly how to control the system to move back and forth between fragments at will.

Related to control is the notion of choice, already discussed in part above. Participant 12 characterized the recommender by saying: "I know you can pick up whatever you want, but probably pick up one these there, and actually you should probably pick up the one that we showed you first." Several people said they did not want to mess up the system or break the story, so they did not deviate from the recommendations even when they wanted to. Participant 1 sums up the difference between choice and control nicely: "I guess picking up all the objects and the tangible…getting to sort of choose what you heard next kind of…although you didn’t really know what you were going to exactly hear...It’s a lot harder to figure out what’s going on than just if you knew what you could listen to next, if I could choose specifically." While the participants had full freedom of choice, they did not know what those choices meant.

4.4.3.3 Proposition 3 Summary

In examining the effect of adaptive components, the following key elements are seen:

Designers

- The designers included adaptivity to support story navigation and narrative understanding
- Different adaptive components were developed to see how subtle differences affect experience

Participants

- Participants show an awareness of adaptivity, but have difficulty putting it into words
- They are uncertain of how their actions might affect the story and how much they have control over
- The participants see value in having a choice of how explore the story, but also feel like the recommender constrains that choice

4.4.4 Reading Glove Discussion

Reflecting on this case as a whole, I return the starting conceptual framework and each of the propositions one more time. I examine the way *awareness* and *interpretation* play a role in understanding user experience in relationship to designer's intentions. I also dig further into the concepts of *control* and *choice* as seen in this study.

4.4.4.1 Proposition 1

In examining proposition one, I was looking to see how well the designers' intentions were reflected in the participant experience, in terms of what benefit was seen in having an adaptive component. The first thing I established was that the system was considered basically usable and enjoyable by the participants, so there were no serious flaws in the design that weighed against a deeper exploration of the data. Next I looked at how participants reflected on their experience of the system and saw that many of them took an active approach to figuring out how the system worked, moving through a series of stages in orienting, exploring, re-evaluating, and then wrapping up. This shed some light on the various ways they *interpreted* the adaptive components over the course of their interaction, but also highlighted how much active interrogation of the system's workings was going on. The designers' goal with the adaptive component was to support story understanding and assist participants in figuring out how the non-linear narrative could be navigated. The evidence that participants spent so much time and effort figuring out how the story delivery worked as well as piecing together the actual narrative suggests that another good use of the adaptive components would be in guiding participants through the stages of system orientation and exploration.   In the current system, the adaptive components are another element that must be figured out, rather than assisting with the overall flow of the story experience. Finally, I showed that there is evidence that participants were aware of which condition they were in terms of interacting with the intelligent versus random recommenders, but that this *awareness* was largely subconscious. This raises the question of what a "benefit" looks like in a designed system. Do the participants have to be aware of the intelligent components in order to benefit from them? Does being aware enhance the benefit, or obscure it because it makes them try to figure out how it works? People tended to over-ascribe adaptivity, thinking that the system is more intelligent than it really is or that the adaptive components are more pervasive than they are. However, participants were also able to detect, at least on some level, whether or not the adaptive component was really helping them or not and this influenced their feelings toward the system and their actions within it.

4.4.4.2 Proposition 2

Proposition 2 looked at how the tangible components of the system interacted with the adaptive components. When designing the Reading Glove system, the starting assumption was that the fundamental action of the users of the system was to use the tangible interface (the gloves and objects) to access and explore the story and attempt to piece it together. The tabletop display and adaptive recommender was added on top of that basic interaction in order to assist the user, and provide responsiveness to the actions that they took. This starting system model is depicted in Figure 9, and represents a specification of the initial conceptual framework laid out in section 3.2.3 above.

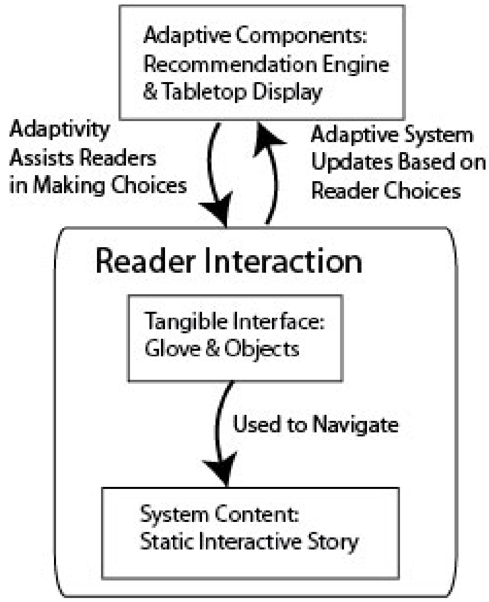


Figure 9. Designers' understanding of the Reading Glove

What the users actually experience when interacting with the system has a number of differing features, however. The distinction between the glove and objects as the interface and the tabletop as a display is not obvious; several participants wanted to interact with the table and get more from it. Similarly, the adaptive recommendations and the story delivery mechanism were often collapsed by the participants. Many participants believed that their actions might be changing not just what was displayed on the table but also what elements of the story they had access to or what lexia were associated with each object. This collapsing of components that seem separate from the designers' perspective creates a denser and less comprehensible overall system model for the participants (Figure 10). I do not mean to say that the participants are "wrong" here, but rather that there are ways in which the design of the system is not conveying useful information to the participants. Elements of the design are activating a set of expectations in the participants that the system cannot always deliver on.

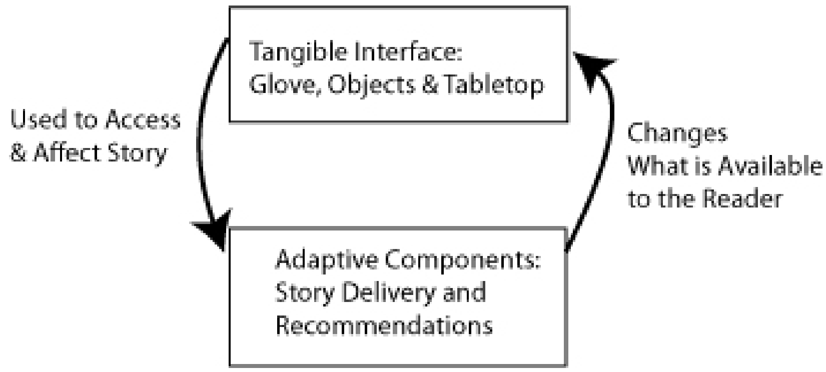


Figure 10. Participants' understanding of the Reading Glove

The presence of the adaptive components complicates the understanding of the novel tangible system, creating a more complex system that is difficult to parse.

4.4.4.3 Proposition 3

Proposition 3 examines what the true effect of adaptivity is by comparing intentions and goals to the actual experience. Evidence from the interview data shows that participants tended to ascribe adaptivity or intelligence to the complex system, but not necessarily to the intended components. One element that stood out in participants' descriptions of their experience was the way that they felt their actions helped to "make the story go". The participants came to view themselves as the motive force, driving the story forward. In this respect, the adaptive component could be seen as inhibiting rather than encouraging the participants ability to make meaningful choices. The presentation of 1-3 recommended objects constrained the choices of the participants, unless they decided to simply ignore the display. While some people did do this, others were worried about the effect this would have and therefore limited their choices to what was recommended.

Another interesting result was the inconsistency of the participants' feelings towards their ability to control the system. I propose that there are two distinct ways of understanding control interwoven into what people mean when they say *control*:

1. Control as freedom of *choice*: since interactors can choose any object at any time, they are directing or controlling the story.
2. Control as knowledge of what will happen, i.e. what story fragment they will get.

When interacting with an object for the first time, the reader does not know what story fragment they will get. On the second time around, they may remember or they may not, as the story is sufficiently long and complex as to not be perfectly memorisable the first time through. Several participants described different strategies they used for choosing objects to try and get a specific fragment, including based on their memory, based on what other objects they think should be associated with the information they are looking for, and based the part of the story they are in. Most people experience the first kind of control, but few experienced control as laid out in the second definition. The introduction of adaptive components typically would be thought to enhance the user's experience of control, making it feel like the system is more tailored to them, but control is clearly a subtler concept that requires more finesse to manipulate. From all of this data and discussion, it seems clear that there is a subtle but distinct misalignment between what the designers of the system intended and what the participants experienced. The recommender, intended as a guide and support structure for navigating the story, complicated the participants' understandings of the story and the system, and influenced their feelings of choice and control within it.

5: Case 2: Kurio

Kurio is a museum guide system intended for use by families and small groups visiting a local history museum together. The interactive guide itself is comprised of a tangible user interface that is distributed over several tangibles with different functions, a tabletop display, and a PDA (personal digital assistant). The Kurio research project took place from 2007-2008; I was a researcher on the project, along with fellow graduate students Greg Corness, Kevin Muise, and Bardia Mohabbati, and faculty members Ron Wakkary, Marek Hatala and Jim Budd. Kurio was designed to explore research questions related to tangible and ubiquitous interaction, constructivist learning, and group interaction (Wakkary et al., 2007; Hatala et al., 2009; Wakkary et al., 2009).

Figure 11. The Kurio tools and tabletop (left) and
a family using the system in the museum (right)

5.1 Kurio Description

5.1.1 Interaction and Experience

The story of Kurio is that the family visiting the museum is a group of time-travellers whose time machine has broken. They must uncover facts about the local area and its history in order to fix the machine and continue their time travel adventures. The best way to describe the experience of using Kurio is by narrating a scenario of a family using it; here the family consists of a mother, Sheila, and her children Kim, age 9 and

Simon, age 7. The family begins at the tabletop display, where they are introduced to the time-travel narrative of the game and view a video that introduces each of the tangible user interfaces and the PDA. From there, they view the broken time map and select the first *mission*. There are 5 possible missions, each of which relate to a specific exhibit area, and each family needs to complete three of the five possible missions to fix the time map. When the first mission is selected, the table sends a message to the server and receives back the first set of individual *challenges*. The server is preset with each member's age and name, allowing it to select the appropriate starting level of the challenges. For example, Kim has been assigned a challenge with the listener, while Simon has a pointer challenge. Each tangible has a specific function in terms of the information it can access: the pointer selects museum artifacts, the reader selects text from museum didactics, the listener plays audio clips in different locations in the exhibit, and the finder provides directional information for particular exhibits. When tangibles are assigned to an individual, the tangibles glow green, indicating that they are ready to be used. Sheila, the mother, is asked to collaborate with and help her children for the duration of the first mission. She is given the PDA and her role is to coordinate and facilitate the completion of the challenges by the other group members.

Once everyone has been assigned a challenge and a tool for the mission, the family leaves the table and head out into the museum space. Simon's challenge asks him to "Find objects in the First Nations area made out of parts of animal". As he walks through the First Nation's exhibit, he notices that the tip of the pointer glows blue instead of green when he points at certain objects. When he presses the button on the pointer, the PDA that Sheila is carrying chimes and displays the object that Simon has just picked up. Together, she and Simon can look at a photo and short description of the object and decide whether or not it is the answer he was looking for. They can also call up Simon's challenge objective if he's forgotten what it is. Simon decides he wants to select something different, so Sheila deletes the object from the PDA and Simon's pointer is re-activated.

Meanwhile, Kim has continued exploring and discovers that her listener turns blue at the tip when she stands near the canoe. She plays the listener by pressing a button on the tangible. She hears a sound clip describing how First Nations fishermen would hunt using nets and canoes. She selects this clip as the answer to her challenge, and then goes over to Sheila to see if her mom agrees with her decision. They both think it is the correct answer, so Sheila selects the “review” button at the bottom of Kim’s challenge screen. She answers two quick questions about how difficult Kim found the challenge and whether anyone helped her answer it. Kim is assigned a new challenge and goes back to the table to exchange the listener device for the reader.

Kim and Simon continue doing challenges until the PDA informs them that they should return to the table. Once there, they can view the results of their work. Challenges that were completed successfully are shown as puzzle pieces that fill in part of an image, while incorrect answers are displayed as red puzzle pieces on the side of the screen. The family can review this information and discuss their progress. Next, the system either assigns a new round for the same mission, or moves them on to the selection of the next mission, depending on how much time they have spent so far. At the end of each mission, they are able to view a short “reward” video that gives them more information about the area of the museum they just finished exploring. When the next mission begins, the PDA is switched over to Kim and Sheila gets to try out the tangibles. In this manner, they complete 3 missions, fix their time machine, and are able to continue on to the future.

5.1.2 Technical Details

The Kurio system has 4 main components: the handheld tangible tools, a tabletop system, a PDA, and a server containing the reasoning engine. Figure 12 shows the information that is exchanged between all of these parts of the system. The tangibles, PDA and table system all communicate wirelessly with the server using an XML-based message exchanged protocol. The tangibles are custom designed devices with shells produced on a 3D printer. Inside the shells, the processing is done on a Gumstix prototyping board programmed in Python and running a Linux OS and a Mini-Arduino using the Arduino programming language. Multi-colored LEDs are used for confirmation and feedback to the user. The tangibles identify objects in different ways depending on the type of device. The pointer, listener, and finder use IR sensors that detect IR beacons placed next to museum artifacts. The reader incorporates an embedded RFID reader that reads RFID tags encased in a small icon fastened to the didactics in the museum.

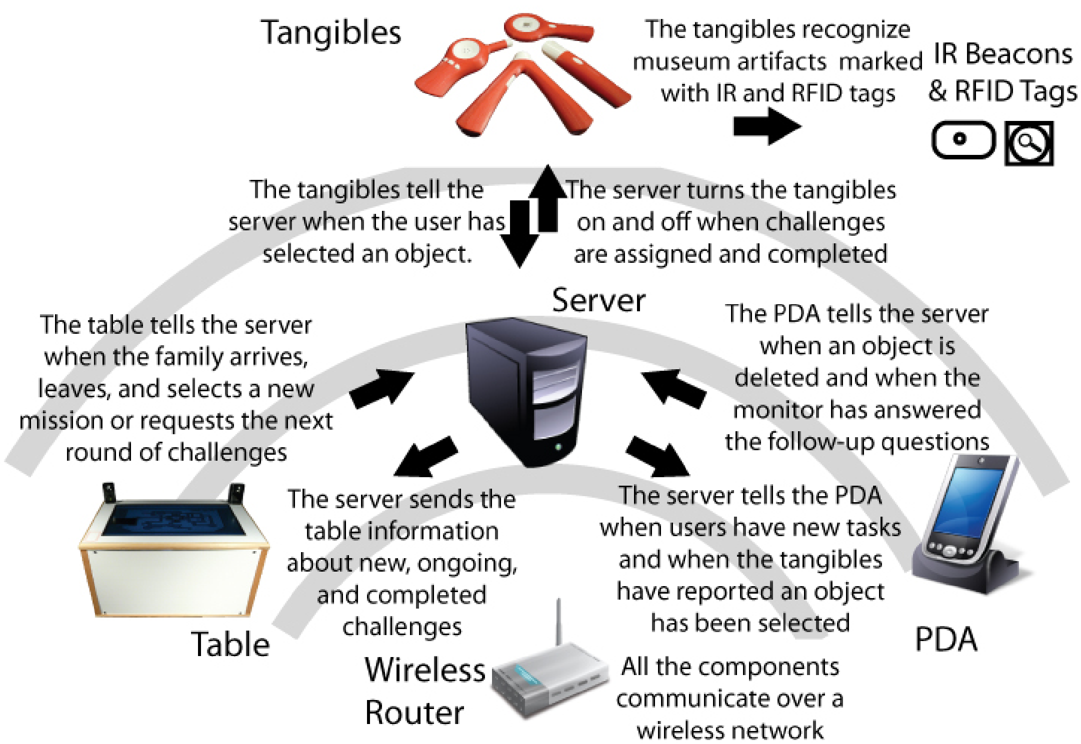


Figure 12. The information flow between Kurio system components.

The PDA is an HP iPAQ running MS Windows Mobile 5.0. The tabletop display is connected to a Mac Mini. Both the PDA and the tabletop applications use the mobile and desktop versions of Adobe Flash. The rule-based reasoning engine is implemented in Jess (embedded Java reasoning engine). The rules operate on an ontological conceptual model in OWL (Ontology Web Language) representing the learning and user model, tasks, game, and artifacts.

5.2 Kurio Study

To evaluate the Kurio system, small family groups tested the system in a local history museum with 58 participants in total, grouped into 18 families and spread across two phases. The goal of the user study was to look at how well the system integrated into the museum and the family's normal way of visiting the museum, and what they felt they learned from using it. There were also a handful of specific probe questions on the challenges aimed at determining the effect of the user modeling component.

5.2.1 Study Protocol

The evaluation of the system was performed in two phases three months apart, using the same protocol. The second phase differed from the first one in that it had a more robust version of the system. There were a few small adjustments to the design of the tangible devices, such as a recessed on/off switch and reducing the number of control buttons on the listener from three to two. For phase 2, the user modeling component was also updated in several ways. The bootstrapping values and some parameters in the group user model were adjusted, especially related to timing of the session to achieve about the same experience for families with different number of people. . A user session consisted of the families completing the game by repairing the time map (on average 45 minutes). This was preceded by a short tutorial on the system and a brief interview and questionnaire on previous experiences with museums and technologies. Following the session, participants completed questionnaires and a semi-structured interview (See Appendix B for the full protocol). Two separate questionnaires were administered, one for children aged 8 to 12 and one for parents and children older than 13. The questions assessed general perceptions of use, fit of the system with the family, and benefits with respect to learning and enjoyment.

The children's questionnaire was based on Read and McFarlane's *Fun Toolkit* and has fewer, simpler questions (Read and MacFarlane, 2006). The sessions were both videotaped and audio recorded. Lastly, 2-4 weeks after the study and on a volunteer basis, families conducted self-administered audio-recorded interviews based on a provided script. Not all of the self-administered interviews were returned. Additionally, difficulties with the audio recording system meant that some of the audio data was lost or recorded at such poor quality that it could not be retrieved. The following analysis uses as much of the data as was available from the questionnaires, interviews and in-museum recordings.

5.2.2 Data Collected

As discussed in Section 3.3, several different forms of data were collected. Table 4 shows how each research question was broken down into smaller investigations using specific parts of the Kurio data.

Table 4. Kurio research questions and data

Research Question	Data Collected
1. What are the expected and actual benefits to the user experience that come from including adaptive components in ubiquitous and tangible systems?	
Do the participants find the system basically usable and enjoyable?	Interview & Questionnaire
How did participants feel about the difficulty of the challenges assigned to them by the user model?	Interview & Questionnaire
How do participants describe the system and the adaptive components in particular?	Interview
What were the designers' intentions in terms of participant experience?	Design Documents & Papers
2. How do the adaptive components support or complicate the ubiquitous and tangible system elements?	
What do participants think about the handheld devices and tabletop?	Interview & Questionnaire
What were the designers' intentions in terms of the tangible interaction?	Design Documents & Papers
3. How do the goals and intentions of the designers of adaptive and ubiquitous systems compare to the actual experience that users have of the designed system?	
What was the goal of the designers for the adaptive components?	Analysis of Proposition 1 and 2
How do the intentions and the actual experience compare to each other?	Analysis of Proposition 1 and 2
If the intended benefit is not seen, how is adaptivity experienced?	Interview & Questionnaire

The interview questions and surveys given to the participants are in Appendix B.

5.2.3 Units of Analysis

The first unit of analysis in studying this system is the designers. Kurio was a collaboration three faculty members: Ron Wakkary and Marek Hatala from Simon Fraser University and Jim Budd from Carleton University. Each faculty member spearheaded an aspect of the project: Ron handled the learning and interaction design, Marek focused on the adaptive component, and Jim dealt with the industrial design and fabrication of the tangibles. There were a number of graduate researchers involved as well. Greg Corness did the electronics and sensors for the tangible tools; Bardia Mohabbati programmed the PDA device and communication protocol, Kevin Muise designed the educational content and graphical elements, and Karen Tanenbaum developed the reasoning engine for task assignment. The project took place from 2007-2008 and was supported by a grant from Canadian Heritage.

The second unit of analysis is the participants of the study. The number of participants was 58 parents and children, or 18 families. The family sizes ranged from 2 to 4 people and in a few cases a family friend joined the group. In most cases, a single parent accompanied one or more children, but in one case two parents participated. There were 35 children between the ages of 7–12: 20 boys, 15 girls. There were 4 children between the ages of 13-17: 2 boys, 2 girls. And there were 19 parents (15 mothers, 4 fathers) ranging in age from 24 to 57. The families were recruited from the local area by way of mailing lists and notices circulated at the local schools and homeschooling groups.

5.3 Adaptivity in Kurio

The story above gives a flavor of how the Kurio experience progresses. The reasoning engine on the server is what guides the course of the game, keeping track of everything that happens and making decisions based on that information. There were two main goals in mind in terms of how to customize the game experience for each family:

1. To find the appropriate challenge level for each individual, and
2. To manage the length of the mission rounds to suit the pace of the group.

At its core, the reasoning engine is a rules-based expert recommender system, supported by a knowledge base consisting of an ontology of the available missions and challenges. A set of individual models as well as a group model is maintained throughout the course of each family's interaction with Kurio.

5.3.1 Individual Models

The individual models consist of some basic demographic information (name, age, family name) and a set of values for specific learning-related skills. Bloom's taxonomy was used to structure the learning model; the taxonomy progresses through 6 levels of learning: Remember, Understand, Apply, Analyze, Create and Evaluate. (Anderson and Krathwohl, 2001). Each individual challenge is categorized according to which level of the taxonomy it relies on most. The age of the individual participant is used to set the starting values for the skills.

Table 5. Starting skill values based on age

Level	Under 10	10-13	14-18	Adult
Remember	0	1	1	2
Understand	0	.5	1	1
Apply	0	0	.5	1
Analyze	0	0	0	.5
Create	0	0	0	0
Evaluate	0	0	0	0

When a new challenge is to be assigned, the reasoning engine ranks all possible challenges and chooses from amongst the ones that are the best fit. Three criteria are used to automatically rule out certain challenges: current mission, tangible availability and age.

Current mission: If the challenge is not part of the current mission, then it is not considered for assignment. Each mission has between 18-24 challenges.

Tangible availability: Any challenges requiring a tangible that is already in use are discarded from the pool of candidates. Therefore, if Kim is doing a challenge with the reader, Simon will not be assigned a new challenge using the reader. In each mission, there are between 3-7 challenges for each tangible.

Age: The listener was more difficult to use than the other tools, both in terms of interface and the cognitive requirement to listen to and extract information from the audio. Therefore, an age limit was set so that children under the age of 9 did not get assigned challenges using the listener. Once these hard criteria have narrowed the pool to challenges, a ranking algorithm assigns each candidate a value based on 3 other factors: skill progression, skill reinforcement, and variety. Each factor contributes either a high, low, or neutral ranking to the candidate challenge. After the rankings for all factors are added together, the highest candidate is assigned as the new challenge.

Skill progression: This factor is designed to encourage a steady increase in the skill level of the challenges, based on the skill of the previous one. If the candidate challenge is one skill higher than the last challenge completed, then it is given a high ranking because it is a logical progression. If it is more than one skill higher, it is given a low ranking because it would be too quick of a progression. If it is the same skill or lower, it is given a neutral ranking because it represents no or backwards progression.

Skill Reinforcement: This factor tries to make sure that the challenge level does not increase too quickly, requiring the individual to have a certain number of "points" in the lower level skills before being assigned challenges involving higher level skills. This factor looks at the skill used by the candidate challenge and compares it to the stored value for the individual for both that skill and for the skill that is one level lower on the taxonomy. If both the stored value for the candidate skill and the lower skill is less than 2, then the candidate challenge is given a low ranking, since this would be presumed to be hard for them to do. If the lower skill is greater than 2 and the candidate skill is less than two, it is given a high ranking since this is ideally suited. If both skills are over 2, it is given a neutral ranking since it will probably be easy.

Variety: This factor looks at whether or not the individual just used that tangible. A slight preference is given for switching to a new device, to prevent boredom or the perception that one person is "hogging" a specific device. This factor mostly functions as a tie breaker between candidates that are evenly matched in terms of other factors.

Example: The description of the ranking logic above may be a little confusing, so here is an example. In this example, the previous challenge completed was at the level Understand and used the listener device. The relevant part of the individual's model is currently: Remember: 2; Understand: 1; Apply: 1. A low ranking is +10, a neutral ranking +30 and a high ranking +50.

Table 6. Example candidate ranking for a new challenge

Challenge	Progress	Reinforce	Vary	Total
Remember Reader	+30	+30	+10	70
Understand Listener	+30	+50	+0	80
Understand Reader	+30	+50	+10	90
Apply Listener	+50	+10	+0	60

Table 6 shows the rankings for four different candidate tasks according to each factor. The challenge using the Reader at level Understand would be assigned, since it reinforces the current level. If that challenge is completed successfully, the understand value of the model would increase, and the next time around an Apply challenge would be likely to be assigned, as it would increase the individual's skill now that Understand has been reinforced. The use of a ranking system for these factors instead of a binary "yes" or "no" allows the system to degrade gracefully if optimal challenges are not available. For example, if many of the mission's challenges have been completed already, the system may end up assigning a lower ranked challenge that ordinarily would be considered too "easy". This was judged to be preferable, however, to just running out of challenges and not having anything to assign.

The table above gave the starting skill values for each age group, but of course those levels are continually adjusted throughout the gameplay to reflect an individual's progress. Each time a challenge is completed, the value for the skill associated with that challenge is updated in the user model. Three factors determine how the value is changed: whether or not they answered correctly, whether or not they got help in completing the challenge, and whether they rated it easy, just right or hard. Table 7 shows the effect of a completed challenge on the user model value for the challenge's skill.

Table 7. Effect of challenge completion on skill value

	Correct		**Incorrect**	
	Help	**No Help**	**Help**	**No Help**
Easy	+1	+1	-.5	-.5
Right	+.5	+1	-1	-.5
Hard	+.5	+.5	-1	-1

5.3.2 Group Models

Compared to the calculations involved in the individual model, the group model was quite simple. The primary thing the group model tracked was progress through each mission. Progress was calculated as a percentage out of 100. Each time a challenge was completed, or 5 minutes passed, the progress was incremented by a certain amount. When the progress reached over 60%, challenges stopped being assigned and the group was instructed to return to the table when all current challenges were completed. The group would thus typically return to the table with 60-80% of the mission completed. After reviewing the challenges completed during the first round, a second round would be assigned to bring the total up to 100% through the mission. The amount of progress that each challenge counted for was determined by the number of people in the group. In a two person group, a challenge contributed 20%, while in a 3 person group, it contributed 15%. This kept smaller groups from having to do more challenges to finish a single round. Every 5 minutes that passed also added 15%. Using both challenge completion and time passage to increment the progress counter helped prevent slower families from getting frustrated or feeling trapped within a single round. Slower groups who were perhaps experiencing difficulty completing challenges did not have to do as many challenges as faster groups, since the passage of time also increased their progress through the mission.

5.4 Kurio Analysis

5.4.1 Proposition 1: Intended Benefit vs Actual Experience

The first proposition that I am investigating with this case study is that *Designers have a greater belief in the benefits of adaptive components than the users experience*. In this section, I look at data from post-session interviews and questionnaires to understand how participants experienced the system.

5.4.1.1 Designers: Intended Benefit of Adaptivity

One of the early mission statements of the Kurio research project was to develop an interactive system that supported groups in the museum. Many of the digital applications for museums today are individual, typically consisting of audio guides requiring headphones that direct a visitor around the space or allow them to wander and punch in codes next to specific items to learn about them. This experience isolates the visitor from others in the museum, which is problematic since the majority of museum visitors are in family groups (Wakkary et al., 2007). Three research strategies were used to address this problem. First, the researchers looked at ways to use embodied interaction to create a fun and playful system that was useable by children as well as adults and that engaged multiple senses and bodily action in the exploration of the museum space. Second, they focused on game-based learning as a way to engage families with the museum content in a non-didactic way, using adaptive and intelligent techniques to model group dynamics and roles to create an experience focused on social interaction rather than isolation. And finally, they developed a hybrid system making use of a range of different modalities, including handheld devices, a tabletop computer, and a distributed sensor network (Wakkary et al., 2009).

The development process for the Kurio system started with an ethnographic study museums in general and of the Surrey Museum, the local heritage museum where the system would be installed, in particular. The goal was to get a better understanding of the kinds of museum experiences that currently existed in order to better design a guide system that enhanced rather than worked against current practices of heritage exploration. Researchers from the project visited two museums in the local area that did not have any technological enhancements, the Maritime Museum and the Vancouver Museum, and two museums in the Pacific Northwest that had guide systems in place already, the Museum of Anthropology at the University of British Columbia and the Experience Music Project in Seattle, Washington.

Prior to starting design work, the researchers also conducted a lengthy study of the Surrey museum, starting with expert interviews with the museum manager, education specialist, exhibit preparator, archivist, reference specialist, publicist and public program specialist. All of these staff members gave video recorded tours of the museum to get a sense of how they told the story of the museum content to visitors. Finally, the behavior of families in the museum was studied, in the form of field observation from a distance as well as more targeted “go-alongs” where researchers followed a specific family as they explored the exhibits. All of these experiences with the museum space yielded a wealth of information about families visit the museum and what the character of the Surrey museum was.

In designing the adaptive components in particular, there were two main goals:

1. To find the appropriate challenge level for each individual, and
2. To manage the length of the mission rounds to suit the pace of the group.

As described in section 5.3 above, the individual user models used Bloom’s taxonomy to track and adjust each person’s skill level in different areas. This information was used to assign new challenges. At the group level, the completion of the level and the number of tasks completed was tracked alongside the elapsed time to determine when the optimal time was to bring the group back to the table or to start a new round.

5.4.1.2 Participants: Actual Experience

All the study participants commented that playing the game was a fun and engaging way to experience the museum. Figure 13 shows answers from each of the questionnaires on questions about how fun the system was.

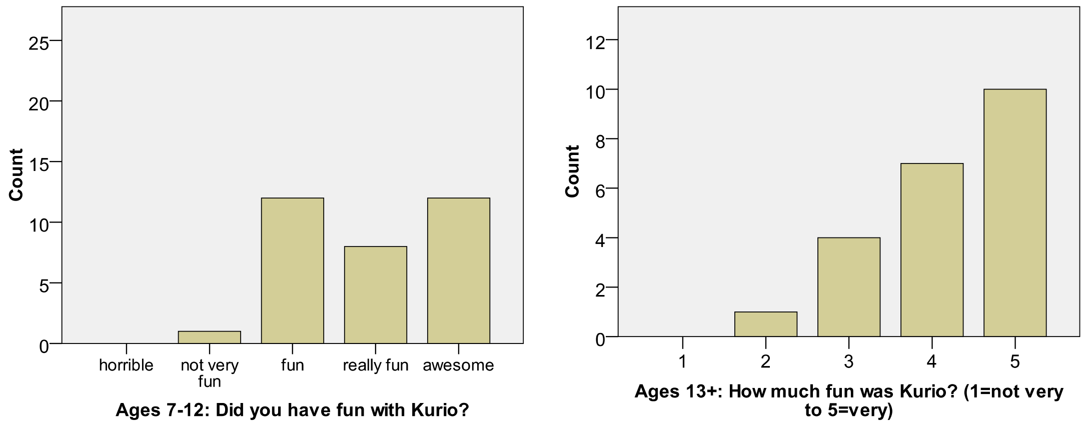


Figure 13. Post-session questionnaire responses from Kurio

Many parents commented on the fact that the game provided them with a way to linger over and reflect on particular pieces of information that they were sent to collect. One mother said

> "It was easy to use, it was fun to use, the technology, and it was, like it forced you to slow down a little bit and look really at things. And try and think about things in a different way, maybe, than you... it wasn't just that you were just taking in the information, it's that you're trying to take in the information and to think about it a little bit to figure out the answer to the question." (Family 5, PI)

Some parents did note that while the game deepened their knowledge of specific elements related to the individual challenges, it was a distraction from taking in the museum as a whole or from noticing exhibits and objects outside of the game's direction. A mother said:

> "Yeah, well, we didn't really get a chance to, like I would have done what Andrew would have done, read things a little more carefully, and this, that was that was one drawback I mentioned about this, this type of system that focuses you on completing the task, so there's lots of information that you missed, because you just exclude it, because it's not what you are looking for. And so, and in that way... and you know, I kind of kind of hurried by things." (Family 11, PI)

One of the primary goals of the project was to develop a system that could be used as a group and that did not isolate family members from one another. Kurio definitely did require teamwork and group coordination, a fact remarked upon by several parents. One mother reflects during the post-session interview:

> "I like that it just kind of got us all working together on something. I thought that it is fun for families because the parents can work with the kids and everyone, um, I don't know instead of just kind of feeling like you are dragging your kids around a museum and saying "look at this, look at this" you're all engaged in it and the kids are on equal footings too….I didn't know any more than them. And we were all, just we were all kind of equal. and the kids could often find things before I would find them. And I would like that they could find it and tell me about it I think that they get more excited about it if it's something that is "hey look at this" instead of me just telling them about it." (Family 25, PI)

However, there were a couple elements that were still problematic in terms of the group dynamic. The first was the role of the PDA in managing the group progress. Particularly in larger groups, where they might be 3 people completing challenges with their tools, there was a lot of work that the PDA user needed to do to remind people of their objective, confirm what they had picked up, delete it if it was not correct, complete the challenge if it was correct, and then answer the post-challenge questions. Challenge-doers would frequently interrupt each other in their eagerness to see what the PDA had registered from their device, leading to frustration on the part of the PDA user as well as the other people with pick-ups to check. One mother describes her frustration: "But I also think that it would be really good if each person had their own [PDA]….because it's so annoying to have to line up, queue up for the person with the monitor to tell you what the task is or get that information when there are other people also waiting" (Family 9, PI) The second element that could have been improved was the ability of the group to reflect on the challenges and their answers. "When we just found out that we had the answer wrong, but we didn't get what the right answer was, or I don't recall talking about it." (Family 15, SA) One father suggested that even the correct answers were not necessarily absorbed by everyone in the group:

> "The other thing is, is that, they went out and did things on their own, and I wouldn't necessarily even know what the questions were that they were answering. And so, I just wonder if there's an opportunity for a loop somewhere in there somewhere in the system...you know you have the tabs come up with [Person A] did this and [Person B] did this, I just wonder if there's a way that you play those back in a way, in a controlled

> way, so that everybody sitting at the table is kind of forced to look at what the questions were and what the answers were." (Family 11, PI)

The family was able to see the wrong answers when they returned to the table, but they were not associated with the challenge they were intended to answer. An explanation of why the answer was wrong and what was correct was sometimes given verbally by the researcher at the table. There was clearly room for providing the groups more of an opportunity to reflect on the challenges and answers they had collected.

5.4.1.3 Proposition 1 Summary

In examining the designers' intentions versus the participants' experience, the following key elements are seen:

Designers

- The designers were exploring the use of embodied interaction, social interaction through game play, and a hybrid system to promote engagement with the museum
- The research started with a survey of existing museum technology and an ethnography of the museum the system was being designed for
- The goal of the adaptive components was to appropriately challenge the individuals, and to manage the overall flow of the game to suit the group

Participants

- The participants reported enjoying playing the game
- Some were uncertain whether it was a distraction from the museum itself
- The game required teamwork, but there was a bottleneck at the PDA
- Correct and incorrect answers were not provided in a way that allowed the participants to reflect on the information and learn from it.

5.4.2 Proposition 2: Interaction with Tangibility & Ubiquity

Proposition 2 states that: Designers believe that adaptive components can increase the ease of use or enhance learning or other experiential elements of ubiquitous systems, but in fact the adaptive components are more likely to add hidden complications. In this section, I look at conversations amongst the participants about the tangible tools and the museum space, plus some questionnaire data.

5.4.2.1 Designers: Physically Engaging the Museum

Following the study of the museums, the researchers also ran workshops to explore elements of the interaction techniques being considered for the new system. In particular, the workshops explored how to connect physical objects or artifacts with educational tasks or activities. Using areas on campus like the wood working shop and motion capture studio, three workshops were run to explore how to design learning tasks within a physical space. Each of the three workshops asked pairs of participants to assume fictional roles and accomplish tasks and activities related to the roles. The workshops were conducted in rooms that had been “augmented” with paper tags that provided additional information on physical objects in the space. These paper augmentations were meant to mimic the information that would be available in the museum setting via the guide system. The participant tasks typically required moving around the space, collecting specific tags and returning them to a central location. Throughout the course of all three workshops, the amount of collaboration that was required or encouraged by the activity and task structure was varied, in order to see what patterns of interaction would emerge from the different design decisions. Bloom’s taxonomy of learning was used to structure the tasks, just as it would be used in the individual user models in the final system. Each individual task was designed to be at one of these levels, and part of what was investigated was whether individuals felt an increase in challenge and learning level when the task level increased, and also how users on different learning levels could collaborate with each other while constructing knowledge as a group.

The first workshop involved two different rooms: a workshop area with power tools, and a motion capture space with various types of cameras and projectors. This workshop focused on determining if the participants would notice if tasks got more or less challenging. Color-coded information tags were placed on specific objects in each of the rooms, and participants were instructed to only collect the color that they were assigned. The goal for the participants was to develop an understanding of the items in each room through collecting the information cards necessary to complete their assigned task, and then returning these cards to the facilitator. One of the main observations coming out of this workshop was that the participants brought back tags other than the ones intended when the tasks were designed. This occurred despite efforts to constrain the possible answers via careful task writing and a limited set of available tags. It became clear that assessing right and wrong answers based on a given task would be a challenge for a system, since there were always unexpected but reasonable responses from the participants. Additionally, there was little group interaction observed in this first workshop, which may have been due to each participant being told to access information only from their assigned color. This limited the participant's ability to communicate and share information, or help each other complete tasks.

The second workshop introduced the idea of a shared activity, which the individual tasks contributed to, in the form of a puzzle that acted as a representation for their shared learning goal. Each puzzle piece had an image representing an item in the room, and the pieces were placed next to those items along with some explanatory text, as the tags had been in the first workshop. Any participant could choose any puzzle piece. The participants therefore had to negotiate who needed the specific piece more, as there was only one puzzle piece for each item. The puzzle itself could be constructed in multiple ways, with multiple pieces for some positions in the puzzle. However, depending upon which puzzle pieces were combined to create a component, other sections could not be connected in a proper manner. Thus the participants had to negotiate how each individual section would be constructed so that all the sections could be combined. A much greater level of collaboration and interaction was observed in this workshop. In the post-task interviews, the participants noted that they enjoyed the use of the puzzle, and especially the idea that there was various ways it could be constructed, which helped them to reflect upon the activity itself. The third and final workshop used the same puzzle and activity structure, but changed the way in which the participants could combine them and select tasks. The task descriptions were adjusted to create a learning scale, where some activities were simple and others were more complex, based on Bloom's taxonomy. The workshop provided fewer task choices for the participants, attempting instead to provide a level of challenge based on adapting to the participants' learning level. Also, instead of allowing a participant to choose another task once they were finished, they were instructed to help their partner to finish their task. This collaboration strategy was well received and there was little competition observed in the interactions. Having both the participants assembling the puzzles at the table at the same time after completing their tasks created a further opportunity for the two to communicate. In post-task interviews, the participant's reported sense of challenge corresponded to how the researchers manipulated the learning level by restricting their choices to tasks at a certain level.

5.4.2.2 Participants: Tangible Connection to the Museum

One of the stated goals of the project was to focus on embodied interaction by using tangible and ubiquitous technology to support playful interaction with the museum space. While participants did not talk about the technology in those exact terms, of course, there are a couple quotes from the interviews that highlight the way embodied interaction techniques affected their experience. One parent says in the self-administered interview that “So you didn't really get to touch the exhibits, but you've got something in your hands and you felt like you were touching something.” (Family 18, SA) In a different family, one of the boys told the interviewer in the post-study session that he liked the experience because “You get to explore deeper than you usually explore”. When asked to expand on that idea, he said “You actually get to use the artefacts.” (Family 11, PI) Even though there is still physical distance between the visitor and the museum artifacts, the use of the tangible tools connects them to the objects in a deeper way, making them feel like they have interacted with it in some manner.

In order to achieve this interaction with objects in the museum, the display spaces were augmented with sensor tags, either IR beacons placed around the display cases or RFID chip tags placed on the museum didactics and displays. The goal was to place the sensors as close as possible to the objects they were connected to while also making sure they could be triggered from a range of heights and orientations. For the IR devices, there was a fairly narrow range where the beacon would reliably be detected, meaning that participants quickly realized that they had to be aware of exactly where the sensors were placed. This led to an interesting dynamic in terms of interpreting the museum space. Children in particular quickly keyed onto the fact that only some parts of the museum were augmented with sensors, as the Kurio game covered material in approximately one third of the exhibit space. The sensors thus offered meta-information about what was and was not part of the game system, limiting the area of the museum to explore. This has good and bad aspects to it. It did allow for participants to pay less attention to the actual content of the museum exhibits, looking instead just for the sensors. An exchange between a parent and child in the museum highlights this behavior. Girl: “I found kitchens. I found four kitchen sensors.” Father: “Yes, but are we looking for kitchen stuff?” (Family 17, IM) This family in particular seems very aware of the beacons; at another point during the gameplay, the father narrates outloud his search strategy for the answer: “A plow would be one thing. I don’t know, this looks like logging, doesn't it? …Okay, that actually is a plow, but it doesn't look like there's anything on there for… It doesn't look like a sensor. Em, do you see a sensor over here? Okay, can you see if that thing turns that thing blue? No?" (Family 17, IM) He appears to be moving back and forth between looking for specific content (a plow, the logging section) and sensors that indicate an object is technologically accessible. On the other hand, the museum space, despite being small relative to many museums, was sufficiently large that families would occasionally wander off in the wrong direction and fail to find any beacons, leading them to realize that they were in the wrong place. Thus the sensors provided a helpful navigation aid. This is an interesting challenge for ubiquitous computing, where technology is distributed through a space, with the goal of being unobtrusive so as not to distract from the content of the space, while still remaining visible enough to be used when needed.

The custom made tangibles or "tools" of the Kurio system were definitely the most salient part of the experience for most of the participants. In the short answer section of the post-interview, several participants commented that the kids in particular enjoyed the use of interactive technology, and one person said "This is exactly the kind of technology that I would like to see in more museums" (Family 25, PQ). Unfortunately, there were a number of glitches present in the system, affecting nearly every study session to a greater or lesser degree. In particular, the first half of the study was subject to a number of system breakdowns; additional months of development leading up to the second round of study sessions led to a more stable system. Some of the tools had trouble consistently triggering on the beacons or tags present in the space, and frequently there were breakdowns in the communication between the tools and the handheld PDA, where the selected item was supposed to show up. It was possible to recover from these errors by quitting challenges on the PDA or switching out devices, but the fact that the system was unstable definitely contributed to some frustration on the part of the participants during gameplay. In the short answer section of the post questionnaire, numerous people in the first phase complained about the unreliability of the technology and how frequently it stopped working. Figure 14 shows questionnaire results relating to how easy the system was to use and how hard it was to learn. It was not considered "really easy" or "super easy" to use by the youngest participants, and the older ones did not rate it as "required very little effort to learn".

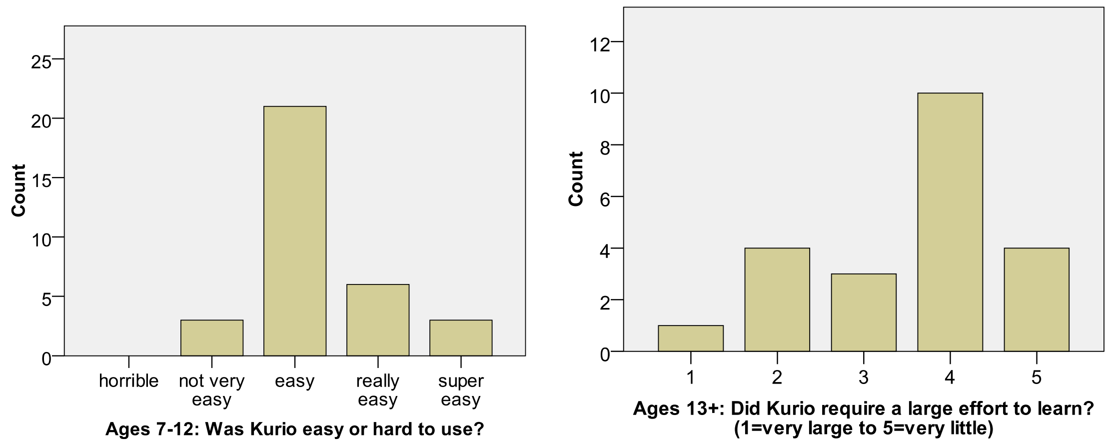


Figure 14. Post-session questionnaire responses from Kurio (pt 2)

Despite these glitches, people still reported enjoying their experience and even wanting to return and use the system again. The novelty factor of the tangible devices was high, leading at times to distraction. During one of the self-administered interviews, the mother asks her sons what they remember doing in each of the areas of the museum completed. One child replies “Yeah, ok, so in the aboriginal we used the pointer and the reader, I believe. Hm. Excuse me. But mm, what we did in those areas? Use the pointers and the finder!”, to which the mother retorts “Cause you were really into the tools and not into the information that we were finding.” (Family 15, SA) While many of the children can recall specific facts they learned about the museum when prompted, using the tools is frequently the first thing that they remember and want to talk about.

5.4.2.3 Proposition 2 Summary

In examining the designer and participant perspectives on tangibility and adaptivity, the following key elements are seen:

Designers

- Workshops were run to explore how to link physical objects with digital information and foster collaboration

Participants

- The tangible devices were enjoyable, but novel to the point of distracting participants from the actual museum and game content
- Technical glitches interfered with learning and trusting the system

- The augmentation of the museum space with technology changed the experience of it, influencing physicality and embodiment

5.4.3 Proposition 3: The Effect of Adaptivity

The final proposition under consideration is: In tangible or ubiquitous systems that utilize intelligent techniques to provide adaptive system responses, the designer's intended adaptive effect differs significantly from the actual experience of the adaptive system by the users. In this section, I look at discussions amongst the participants in the museum as well as the post-session interviews to understand what the impact of the adaptivity was.

5.4.3.1 Designers: Goals of the Adaptivity

As discussed above, the goal of the designers was to promote an engaged experience with the museum through embodied interaction, social connection, and a hybrid system consisting of a variety of components. The physical nature of the tangible devices, the sociality of completing the puzzle as a family, and the augmentation of the museum space all contributed to a constructivist learning approach. The adaptive components were designed to respond to the individual's skills with an appropriate level of challenge, and to manage the overall length of the rounds to suit the group's pace.

5.4.3.2 Participants: Actual Adaptive Effect

The effects of the reasoning engine's challenge assignment mechanism are not much in evidence in the collected data. The novelty of the handheld devices, tabletop system, and gameplay mechanics largely overrode any discussion of the challenges in the abstract or speculation about how and why they were assigned the way they were. Occasionally there was squabbling amongst children over who got which challenge, but this was connected to their desire to use one particular tool or the other. During one study session, a girl complained about her sister getting the PDA device when she wanted it, asserting "Next time, when it's your turn, I get the PDA!", and her father replied "No, Kurio assigns it, so it's random. That's how blind studies work." (Family 17, IM) None of the other families made any reference to how the challenge assignment was done or why. The technical glitches also impacted the reasoning engine component, as the most common way to fix a glitch was to quit a challenge or return to the table with it incomplete; this meant that a portion of challenges contributed either no or inaccurate information to the user model. When a challenge was completed, the PDA prompted for answers to two questions: whether individual had help in completing it, and how difficult they found it. This was supposed to assist in determining whether the challenge was at the right level for individual, so that the next one could be selected with a different skill or difficulty level as needed. In practice, there is some evidence that these questions were not interpreted the way they were intended to be understood. Because of the frequent low level issues with getting the technology to work, the questions regarding help and difficulty may often have been answered with regard to whether or not there was technical assistance or problems during the challenge completion. At one point during a family's session, they reached the end of the first task, after having had some trouble with the PDA and being assisted by one of the researchers to get it working again. The researcher helped complete the questions, asking "Did anyone help? Yup? Was it easy, just right or hard?". The child replies "Easy" and the parent adds "It was easy to use." (Family 23 IM) For both of these questions, they seem to be responding more to the technical elements of challenge completion than the conceptual ones: the researcher had helped them fix the PDA and the tool had been easy to use.

Although there is little feedback on the specific adaptive component of the Kurio system, there are other elements found in the transcripts that are relevant to the design of adaptive and intelligent systems more generally. The first is the notion of surprise. In one of the self-administered interviews, a child is asked by his mother what he liked best about the experience and he replies "Uhhm, being assigned the things, not knowing what you are going to be assigned next, just waiting for what you are going to be assigned, it was going to be a surprise." (Family 11, SA) Other children similarly said that the scavenger-hunt like aspect of being given things to seek in the museum was the most fun part of the experience. So even if they were not consciously thinking about the challenge assignment mechanism, they enjoyed the fact that they were being personally assigned something to do, and that they did not know what it was going to be.

Related to this is an interesting bit of reflection on the branching choices offered to the families as they move through the game. Every family started in the same section of the museum, dealing with the aboriginal people of the area. After completing that mission, the family was given a choice between Blacksmithing or Farming. When they returned to the table after completing their chosen mission, the one they had not picked would no longer be available and they were offered a new choice between Homelife or Forestry. Upon completing their choice from that set, the game was over. Several people mentioned that they found this annoying. They did not like that the game "filled in" the missions they did not do, and wanted to be able to do them all. One child says "In the Kurio time map there I think you should be able to go to all the stations...Yeah, you could pick how many stations you wanted to go to. You could do all of them...Or just one or two...Cause they shut off a few of them, it was just automatic." (Family 18, SA) There is something interesting going on here, where the offering of a choice is perceived as limiting in some manner by shutting down the paths that were not taken.

5.4.3.3 Proposition 3 Summary

In examining the effect of adaptive components, the following key elements are seen:

Designers

- The designers were exploring the use of embodied interaction, social interaction through game play, and a hybrid system to promote engagement with the museum
- The goal of the adaptive components was to appropriately challenge the individuals, and to manage the overall flow of the game to suit the group

Participants

- The technical glitches lead to an inaccurate or underspecified user model
- The novelty of the tangible aspects overwhelmed speculation about underlying mechanisms
- The post-task questions were variably interpreted as being about conceptual vs technical difficulty
- Participants enjoyed the feeling of surprise and the appearance of randomness within system
- They did not like having to choose and thus lose the chance to do a portion of the game.

5.4.4 Kurio Discussion

Reflecting on the Kurio case as a whole, I return now to the original conceptual framework and revise it. I also highlight two concepts coming out of the analysis that tie aspects of Kurio together and relate to the notion of adaptive tangible and ubiquitous systems: *augmentation* and *transparency.*

5.4.4.1 Proposition 1

Based on the designer's conception of the system going into the user study, I have articulated the generic conceptual framework from Chapter 3 into the more Kurio specific diagram in Figure 15.

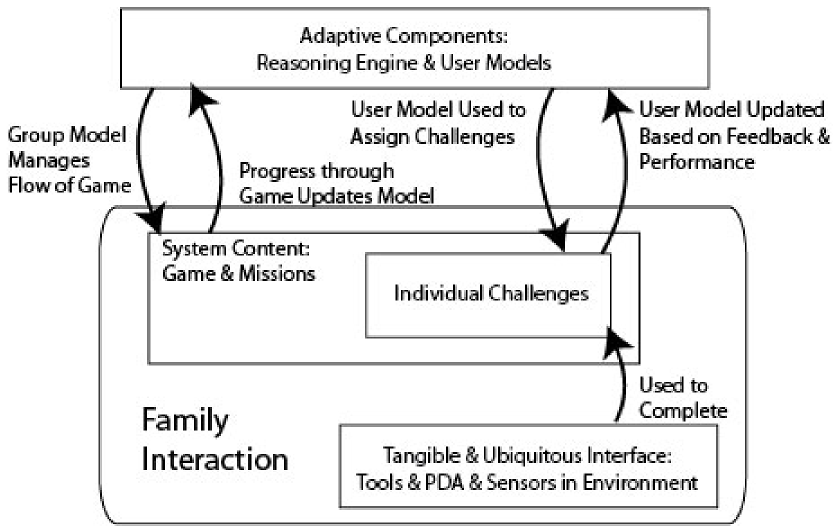


Figure 15. Designers' understanding of the Kurio system

Kurio is somewhat more complex than the Reading Glove, with the adaptive components affecting both the group experience and individual assignments. The tangible and ubiquitous elements are connected to the individual challenges, which the family completes using the tools and sensors in the museum space. In Figure 16 I have attempted to capture elements of the participants' experience of using the Kurio system.

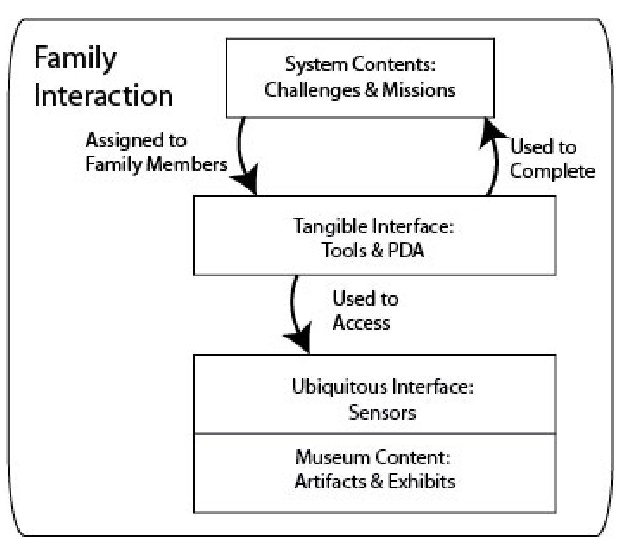


Figure 16. Participants' understanding of the Kurio system

I have split the tangible elements from the ubiquitous elements in this diagram. The tools and PDA were the central focus of the Kurio experience, with the ubiquitous sensors acting as a layer of information on top of the museum content, providing a connection to the artifacts and signalling where the game play took place. These elements were used to complete challenges and missions, but awareness of the adaptive component and its effect on the experience was basically lacking. This is not necessarily a problem, since the goal of much adaptivity is for it to be in the background, but it did make extracting useful data a challenge.

5.4.4.2 Proposition 2

Connected to the tangible and ubiquitous space, a key concept that arises is the notion of *augmentation*. The Kurio system augmented the museum space by overlaying both 1) a physical grid of technology in the form of the sensors and tags that were used to mark out the system's domain and 2) a more conceptual grid of objects to find and collect in order to complete the assigned challenges. The physical grid acted as boundary markers for the "active" portions of the museum, but could also draw attention at the wrong moment, pulling people into spaces that were not yet relevant. There was a tension in both the design and the use of the system where some level of visibility was required for the system to be function (i.e. for people to find where to point their devices), but too much visibility detracted from an engaged experience. When participants started hunting for sensors rather than looking at the actual objects, this was a design flaw. Yet at other times, participants could not find sensors when they needed them due to being placed unobtrusively. This is a challenge faced by ubiquitous computing as a field, as augmenting a space with technology involves a push-and-pull of availability vs. subtlety. There was also a more personalized augmentation taking place with the use of the tools, as they enhanced an individual's ability to interact with and "touch" the museum artifacts in an intangible but real way. The sensory capabilities of the people themselves were augmented by being able to retrieve digital information from the physical environment via the tangible tools. Tangible and ubiquitous technology has the ability to significantly enhance experiences through the augmentation of a space or a person with additional information and capabilities, but understanding how to do that artfully is still an open question.

5.4.4.3 Proposition 3

Relatedly, when considering the experience of adaptivity, the second concept that emerges is *transparency.* There were several places where the transparency, or a lack thereof, of particular information has an impact on the participants' perception of the experience. First is in the time map, where families are asked to choose between different missions. The fact that the unselected missions were later filled in and were no longer an option was a source of commentary. The showing of paths not taken and now unavailable was an irritation, making them feel like they had missed something. While the design goal was to make the system more transparent by keeping all the areas on the map, the families found this frustrating because it showed where they could no longer go. A second place where transparency plays a role is in the post-challenge questions that attempted to find out whether the individuals found the challenge too difficult or too easy. Some of the participants interpreted this question to be related to the technical difficult of completing the task-i.e. how hard it was to use the tangibles or find the object in the space. Since the goal was to interrogate the conceptual difficulty of the challenge question in order to adjust the user model, the variability in interpretation was a problem for the adaptive component. More transparency about what was meant by the question, or what question the participants thought they were answering, would be useful. On the flip side, however, more transparency could cause a problem is in the experience of surprise. Several families reported enjoying the surprise inherent in the assignment of different tasks and devices to the members of the group. Because the algorithm underlying the assignment was hidden, they could not foresee what was coming up next and they enjoyed this "random" aspect of the experience. Making information and inner workings transparent at the right time is a challenge for complex adaptive systems like Kurio.

6: Case 3: Socio-ec(h)o

Socio-ec(h)o is an environment for group gameplay in an ambiently intelligent space. It was an active research project in 2004-2005, exploring questions around intelligent environments, embodied gameplay, audio feedback, and personality types. I was not a member of the socio-ec(h)o research team, which consisted of 5 graduate students: Milena Droumeva, Robb Lovell, Dale Evernden, Malahat Hosseini, and Ying Jiang, and 4 faculty members: Ron Wakkary, Marek Hatala, Alissa Antle, and Jim Bizzocchi. Existing papers on the project discuss the technical details and research motivations underlying the system (Wakkary et al., 2005a; Wakkary et al., 2005b) and present preliminary results from a large user study (Droumeva and Wakkary, 2008; Wakkary et al., 2008a).

Figure 17. Participants using the socio-ec(h)o system

6.1 Socio-ec(h)o Description

6.1.1 Interaction and Experience

Interaction with the socio-ec(h)o system centers around solving riddles by positioning or moving the physical bodies of each of the group members in a specific way. The game is played in a "black box" space draped with black curtains and filled with colored light and sound effects. On the curtained walls, the riddle for each game level is projected. There are 6 levels that can be played, plus an orientation or tutorial exercise. The experience of socio-ec(h)o is best captured by a scenario description from one of the early papers on the project:

> "Madison, Corey, Elias and Trevor have just completed the first level of socio-ec(h)o. They discovered that each of them had to be low to the ground, still, practically on all fours. Once they had done that, the space became bathed in warm yellow light and filled with a wellspring sound of resonating cymbals.
>
> Minutes earlier, the space was very dim–almost pitch black until their eyes adjusted. A quiet soundscape of "electronic crickets" enveloped them. They discussed and tried out many possibilities to solving the word puzzle: "Opposites: Lo and behold." They had circled the space in opposite directions. They stood in pairs on opposing sides of the space. At Corey's urging, the four grouped together on the edge of the space and systematically sent a player at a time to the opposite side in order to gauge any change in the environment. Nothing changed.
>
> Madison, without communicating to anyone realized the obvious clue of "Lo" or "low". While Corey was in mid-sentence thinking-out-loud about the puzzle with Trevor, and trying to direct the group into new body positions, Madison lowered herself to a crouching position. The space immediately glowed red and became brighter. The audio changed into a rising chorus of cymbals – not loud but progressively more pronounced.
>
> Corey and Trevor stopped talking and looked around at the changing space. Madison, after a pause began to say "Get down! Get down!" Elias stooped down immediately and the space became even brighter. Corey and Trevor dropped down in unison and the space soon became bathed in a warm yellow light like daylight. The audio reverberated in the space.
>
> A loud cheer of recognition came from the group, "Aaaaahhh! We got it!" Corey asked everyone to get up. As soon as they were all standing, the space became pitched black again. They dropped down again and the space was full of light. They had learned how to "create daylight" in the space. They had completed level one.
>
> Soon after, a new word puzzle was presented to them in a short video projected on two scrims hanging from the ceiling: "The opposite of another word for hello but never settles." The lights have become very dim now and the audio has a slightly more menacing quality to it. Level two will clearly be more challenging…" (Wakkary et al., 2005b)

There were 6 levels to the game; every group played at least through level 4, while level 5 and 6 were sometimes not completed if time ran out. Each level had an underlying theme, goal, and game skill that it was intended to teach, laid out in Table 8.

Table 8. Socio-ec(h)o levels

#	Theme	Riddle	Goal Body State	Goal	New Game Skill
1	Discovery of light	“Lo and behold”	“high-low”	create day	body position
2	Day for night	“Sloe and low like a plum turtle	“moving low”	create night	movement/ duration
3		“All rolling in a bowl”	“loosely moving”	create day	proximity
4	Rhizome	“Big bang!”	“dense center - scattered edge”	create spring	sequencing
5	Biota	“Gazing over waves”	“gazing over the waves”	create summer	composition
6		“Swaying in the ring of fire”	“ringing around the rosie”	create fall	composition & location

The themes and goals were used to give the gameplay experience a narrative based on natural evolution, but they were not explicitly presented to the participants (Wakkary et al., 2005b).

6.1.2 Technical Details

The socio-ec(h)o system has three main components: the sensing system, the display engine, and the reasoning engine (see Figure 18).

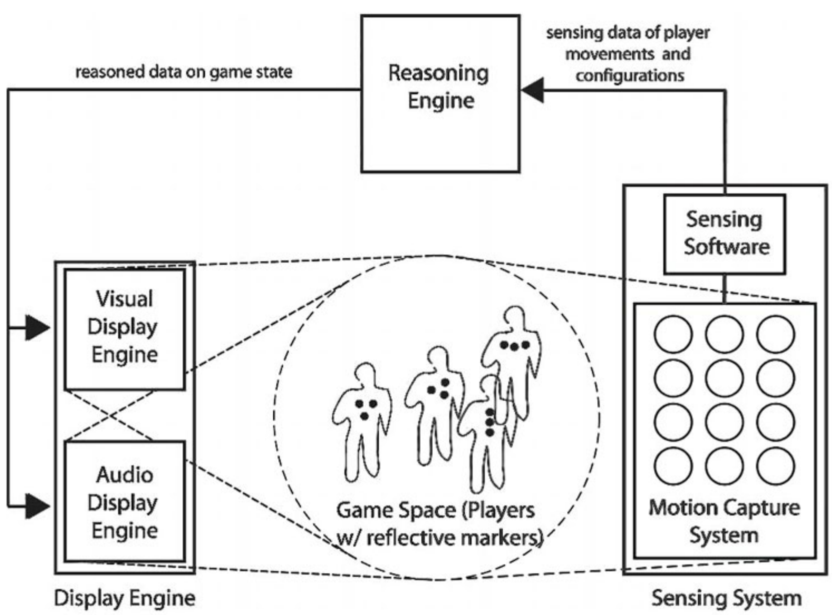


Figure 18. The socio-ec(h)o system diagram from (Wakkary et al., 2005a)

The reasoning engine is discussed in section 6.3 below, while the rest of the components are described here. All following technical details are from (Wakkary et al., 2005a) unless otherwise noted. The sensing system is a 12-camera VICON MX motion capture system controlled by Max/MSP. Each participant wears on their back a set of reflective markers arranged in a unique pattern for each person. The data from the cameras is extracted into parameters such as: “low/high”, “middle/outside”, “fast/slow/still”, “near someone/not near someone”, “travelling/stationary”, “direct/indirect motion, velocity”, “location”, “direction”, “facing north-south/east-west/horizontal” and “visible/hidden”. These parameters are sent to the reasoning engine so that the data can be further interpreted at a higher level than is possible with Max/MSP. All communication between the components is done via the UDP communication protocol.

The reasoning engine then outputs the results of this interpretation, depending on the game status, as control commands to the lighting and audio system. The audio system is also programmed in Max/MSP as a “sound ecology” unique to each game level. In addition to conveying something about the nature of each level, the audio system provides feedback on how close the group is to finding the level solution. The resulting ambient soundscape provides continually shifting, responsive, environmental sound. The audio feedback was designed to move away from “sound/no sound” responses towards a more continuous response system that was described as an “intensity-based gradient sound feedback model” (Droumeva and Wakkary, 2008). There are three components to the audio system: a unique, layered soundscape for each level, an anticipatory feedback signal indicating an approach to the goal state, and a confirmatory signal indicating that the goal has been completed. The last two elements are the same for each level, but the first component was varied for each level both in terms of the content of the soundscape and how the “intensity” response was signalled. For example, Level 3 has a “clinking pebbles” soundscape and indicates increasing intensity via changes to pitch, while Level 4 has a “fire sounds” soundscape and intensity is indicated via cross-fades between five different pre-recorded fire soundscapes (Droumeva and Wakkary, 2008). The lighting system uses a DMX 512 controller and is programmed via Max/MSP. A small grid of theatrical style lights and color scrollers create a dynamic and responsive lighting display that is also unique to each level and linked to the group’s progression towards the solution.

6.2 Adaptivity in Socio-ec(h)o

The socio-ec(h)o reasoning engine was written in Jess, a rules-based expert system programming language for Java applications. The reasoning engine takes the individual parameters calculated by the Vicon camera sensing system in real time and interprets them at a higher level to yield an understanding of the overall state of the group. This knowledge is used to manage the narrative flow of the gameplay, adjusting the audio and lighting feedback to respond to the group's progress through the level. The goal of the reasoning engine component is to create a feeling of "ambient intelligence" where the embedding of technology throughout an architectural environment creates a space which can respond to and reason about human action within the environment (Wakkary et al., 2005b). The individual parameters yield group level parameters such as "high-fast-moving" or "middle-low-stationary". These group parameters are then used to computing the state "intensity", i.e. how close the group is to completing the level. Intensity ranged from 0 to 4, with 4 being the completion state for the level. The state had to be maintained for a specific duration of time to count as having completed the level, so a group could reach the completion configuration briefly but not complete the entire level because they did not hold it long enough.

6.3 Socio-ec(h)o Study

6.3.1 Study Protocol

Each study session took between 2 to 3 hours, and was audio and video recorded. See Appendix C for the full study protocol. The session began with a warmup exercise to introduce the participants to the kinds of puzzles they would presented with and the physical solutions needed to complete them. They were also introduced to the audio cues that would convey information throughout the interaction with the system. Then they played the first four levels of the game without any additional help or intervention. When they successfully completed a level, they were shown a short video animation of the solution they had just found. After the first four levels, they took a short break for rest and reflection, and then completed the last two levels if time permitted. At the end of the session, the participants all filled out a questionnaire about their experience (see Appendix C). Of the 14 groups that participated in the study, the final 6 were given a slightly different protocol. A manual was given to them to use for the first 4 levels (after the introductory tutorial levels). The manual showed a line drawing of the physical configuration needed to complete the level, provided a written description of the solution, and also gave tips on how to perform it. Levels 5 and 6 were still completed without a manual or any other outside help. The manual can be found in Appendix C.

6.3.2 Data Collected

As discussed in Section 3.3, several different forms of data were collected. Table 9 shows how each research question was broken down into smaller investigations using specific parts of the socio-ec(h)o data.

Table 9. Socio-ec(h)o research questions and data

Research Question	**Data Collected**
1. What are the expected and actual benefits to the user experience that come from including adaptive components in ubiquitous and tangible systems?	
Do the participants find the system basically usable and enjoyable?	Interview & Questionnaire
How do participants describe the system and the adaptive components in particular?	Interview
What were the designers' intentions in terms of participant experience?	Design Documents & Papers
2. How do the adaptive components support or complicate the ubiquitous and tangible system elements?	
How do participants interact with the environment?	Observed Behaviour
What do participants think about the riddles & environment?	Interview & Questionnaire
What were the designers' intentions in terms of the environmental interaction?	Design Documents & Papers
3. How do the goals and intentions of the designers of adaptive and ubiquitous systems compare to the actual experience that users have of the designed system?	
What was the goal of the designers for the adaptive components?	Analysis of Proposition 1 and 2
How do the intentions and the actual experience compare to each other?	Analysis of Proposition 1 and 2
If the intended benefit is not seen, how is adaptivity experienced?	Interview & Questionnaire

The interview questions and surveys given to the participants are in Appendix C.

6.3.3 Units of Analysis

The first unit of analysis is the researchers. Socio-ec(h)o was designed over the course of two years, from 2004 to 2005. It was led by 4 faculty members: Ron Wakkary, who developed the interaction model; Marek Hatala, who worked on the reasoning engine; and Alissa Antle and Jim Bizzocchi, who both assisted in the early stages with the embodied elements of the interaction and the gameplay aspects. The team also included 5 graduate students: Milena Droumeva, who worked on the sound design; Robb Lovell, who worked on the motion tracking and lighting aspects; Dale Evernden, who was responsible for participatory design workshops and interaction design; and Malahat Hosseini and Ying Jiang, who both worked on the data analysis.

The second unit of analysis is the study participants. The socio-ec(h)o system was tested with 56 participants in groups of 4 people each. The participants in the study were primarily undergraduate and graduate students at the School of Interactive Arts & Technology at Simon Fraser University. Participants ranged in age from 18 to 49, with the majority being between 18 to 24 years of age, and the gender balance was 16 women to 40 men. Prior to the study, all the participants completed Kiersey's Temperament Sorter and were categorized according to temperament or intellectual type, which was then used to assign them to groups for a specific study session. One of the original goals of the study was to look at the effect of different combinations of temperament on game play and game experience, but results along these lines proved difficult to tease out (Wakkary and Hatala, unpublished).

6.4 Socio-ec(h)o Analysis

6.4.1 Proposition 1: Intended Benefit vs Actual Experience

The first proposition that I am investigating with this case study is that *Designers have a greater belief in the benefits of adaptive components than the users experience*. Here I examine what the designers of socio-ec(h)o intended the experience of the game to be, and how that lines up with what the participants actually experienced by looking at conversations during game play and numerical information on how long each level took.

6.4.1.1 Designers: Intended Benefit

One of the stated design goals of the project was to explore elements of "aesthetic interaction" through a play experience that facilitates discovery. The game interaction was designed to support rich ambiguity and facilitate an open, interpretative space (Wakkary et al., 2005a). The game was developed with simple rules capable of handling a great deal of variation on how the goals are achieved (Wakkary et al., 2008a). The experience of the game was deliberately underdetermined; for example, the choice was made to attach sensors only on backs of the players to allow for expressive gesturing and rich communication between the players that would be hampered by full body sensing. The participants were also intentionally not given much instruction on how to interact with the system. They were supposed to learn what behaviours it responded to by testing and exploring the effect of various movements and patterns. The levels were staged so that each one encouraged the use of a different kind of action: position, movement, proximity, etc. One of the stated research goals was "to understand how to support groups of participants as they learn to manipulate an ambient intelligent space, as well as to better understand how to design ambient components of a responsive environment capable of providing this type of support" (Droumeva and Wakkary, 2008).

6.4.1.2 Participants: Actual Experience

One of the central experiences of the game is engaging with the riddles projected on the walls in order to figure out what movements and positions the system is looking for. Much of the gameplay experience of the participants related to puzzling out the clues and exploring different physical configurations. For nearly all the groups, the first two levels of the system are relatively unproblematic. Level 1's "Lo and behold" requires the group to crouch and remain still for several seconds, which is both a simple solution to enact and a simple riddle to interpret. The second level's riddle is "Sloe and low like a plum turtle", which caused some initial confusion in many of the groups. The word "Sloe" is not a common one, and the font used to write it made it a little hard to read. Most groups quickly found the solution to the riddle, which was to move slowly on all fours in a circle. Even as they completed the puzzle, however, they often expressed some lingering curiosity over the presence of the word "plum" in the riddle, which did not seem to map to an aspect of the solution.

Level 3 starts with the riddle “All rolling in a bowl” and is the first level where groups start to get hung up for significant amounts of time; the longest time here is 13 minutes, but most solve it in 5 minutes or less. The first instinct of many groups was to roll on the floor, but they quickly realized that this was problematic due to the sensors on their back and discarded it as an option. The next common guess is to have each group member spinning in place. When this does not work, the group takes some time to ponder what could be meant by the use of the word “bowl”, and they start to experiment with different options for creating a bowl-like shape with their bodies. One group attempted a complicated weaving and ducking process where they stood in a circle facing each other, and then crossed in opposing pairs to the other side of the ring, crouching low in the middle and thus creating a kind of bowl-like shape if one were to abstract their positions over time. The goal state the system is looking for is for the members to all be moving quickly around the edges of the play area at some distance from each other; in practice this usually is achieved by running in a circle. Several of the groups who try more complicated solutions like the weaving and ducking expressed some dismay at the end of the level that it was “so easy” and they realized they had been “overthinking it”. This is also the first level where some groups trigger the end of the level by doing an action that does not match the animation they are shown, which represents the desired solution. This undermines their trust in the system a bit as it appears to be recognizing movements inappropriately. The inclusion of the closing animation for each level is a design choice that runs counter to some of the stated design intentions, which were to support free interpretation and allow for multiple solutions for a level. Although the system was clearly programmed to have some flexibility in interpreting the completion state, the presentation of a single solution at the conclusion of the level contradicts that goal.

Level 4 is the level that causes groups the most grief, although a couple get through it quite quickly. Four groups take longer than 40 minutes to work on the level, and some do not succeed in solving it by the end of the time. The riddle is “Big Bang”, and the desired solution is for the group to crouch together in the center of the play space absolutely still for a period of time, and then move backwards to the edge of the circle and stand still within 15 seconds of leaving the center. Most groups try some version of the correct solution early on, but the solution parameters for the level seem to be set much more narrowly than previous levels. Whereas level 3 could be completed with configurations that did not match the target solution, level 4 was difficult to complete even when the participants knew exactly what to do because they had the manual. The group was required to hold the starting crouching position for 3 seconds before exploding backwards; if the timing was off they would fail to complete the level. Despite getting close to the solution early on, several successive failures in a row would cause most groups to move onto a series of unproductive tangents instead of narrowing in on the correct sequence. Like level 3, these issues also undermine the goal of interpretative interaction and multiple possible solutions, although in a different way. The narrowness of the solution space for Level 4 cuts out any opportunity for more free interpretation of the riddle. One interesting thing about this level is that it is the first to induce significant amounts of discussion of different metaphors to describe possible group movement patterns. Several groups try configurations based around the solar system and planets circling a sun; others discuss nuclear fission, with an atom splitting off from a molecule, as well as fire, a gun firing a bullet, and rolling dice. The groups that take a long time to work on this level begin to vent their exhaustion and frustration to each other at the end.

Level 5 also causes some groups difficulty, although this mostly seems to come from the interpretation of the clue rather than the technical implementation of the solution. The riddle is “Gazing over waves”, but the final solution does not bear much resemblance to a wave pattern, consisting of 2 people standing in the middle, facing outwards while two others move around the edge of the circle on their hands and knees. Many groups spend a significant amount of time trying to create a wave with their bodies, bobbing up and down in sequence. Level 6 has similar ambiguity problems to level 5; the riddle is “Swaying in the ring of fire” and the solution is to form a circle of 3 people around a single person in the middle. Most groups get bogged down trying to either all sway together or to replicate a fire like motion with their bodies. Like level 3, it is possible to solve both level 5 and 6 with a configuration that does not look like the solution that is shown at the end, making level 4 even more of an anomaly. Not all the groups reach level 6 or even 5 because of the amount of time it can take to complete level 4.

The last five groups in the study were provided with a manual to help them through the first 4 levels of the game. This was an interesting element to introduce into the study. While in theory it should have eased some of the frustration the groups felt, particularly with the difficult level 4, it could also have led to the groups with the manual having difficulty managing the final two levels after four levels of being given the “cheat codes". Judging by the simple metric of time-to-completion, the manual obviously had an effect on the levels where it was in use. Table 10 shows the average time to completion for the manual versus non-manual groups for levels 3, 4, and 5. Without the need to interpret the riddle for themselves, level 3 is solved almost immediately by the manual-using groups. Level 4, while completed much quicker on average than the non-manual groups, still gives the manual users some trouble as the solution requires careful timing and coordination. Most interesting is the fact that the time to completion for the next level, where no manual was available to either group, is roughly equal. The manual appears to have had neither a positive nor a negative effect on the ability to interpret the riddles and feedback system in the later levels, although it does make the early levels easier.

Table 10. Average completion times (in minutes) with and without the manual

	Level 3	**Level 4**	**Level 5**
Without Manual (9 Groups)	6.44	22.13	13.89
With Manual (5 Groups)	1.00	3.60	12.60

Two of the groups with the manual experienced a system crash during either level 3 or 4, and wisely used this time to reflect on what the connection was between the riddle content and the solutions the manual had instructed them on. This likely helped them when they faced level 5's riddle without the manual's guidance. One subtle effect that the manual had on the groups given it was that it influenced the way they discussed the solutions and the way they coordinated their actions. The manual specified things like relative position between the players, speed of movement, and height of the players, which gave clues as to what kinds of parameters the system was sensitive to. While the non-manual groups could infer this from the solutions that worked, they had less certainty over what the system was reacting to for any given configuration. The manual groups could be more certain about what the system was looking for, and also were given a vocabulary in the written solutions and tips for discussing how to coordinate their actions as a group.

6.4.1.3 Proposition 1 Summary

In examining the designers' intentions versus the participants' experience, the following key elements are seen:

Designers

- The designers wanted the experience to focus on aesthetic interaction and a feeling of discovery
- There was a deliberate underdetermination of the design and the instructions given to the players, to leave the experience open to interpretation
- One of the research goals was to understand how people learn to navigate an ambiently intelligent environment

Participants

- The focus of the experience was on the interpretation of the riddles
- Some confusion and frustration was caused by a mismatch between the goal state shown to the players and the actual configuration that they used to reach their goals
- The use of the manual influenced the interpretations participants gave to the system and their movements within it

6.4.2 Proposition 2: Interaction with Tangibility & Ubiquity

Proposition 2 states that: Designers believe that adaptive components can increase the ease of use or enhance learning or other experiential elements of ubiquitous systems, but in fact the adaptive components are more likely to add hidden complications. Here I look in some detail at the questionnaire results regarding how participants interpreted the environmental audio and visual feedback.

6.4.2.1 Designers: Intensity-Based Soundscapes

Within the augmented space of the game, audio and light-based feedback was provided to give the participants clues about their progress towards solving the riddle. This aspect of the system was intentionally left rather opaque, as one of the goals of the project was to allow for rich, aesthetic interaction and interpretation within the space. The system was designed with custom soundscapes for each level, along with distinct and unchanging sound cues that signalled approaching the goal state and completing the level. The soundscape was designed to vary in intensity based on how close the participants were to the goal state. The custom soundscapes and the lack of detailed explanation on how they worked was intended to provide an open space for interpretation of the environment and the gameplay. Similarly, the decision was made to track only body position and movement rather than more detailed limb tracking, in order to leave gestures open as a channel of communication between the participants.

6.4.2.2 Participants: Making Sense of the Environment

Above, I discussed how the participants grappled with the riddles and their interpretation, but there was another interpretation task going on at the same time: understanding the visual and audio feedback provided by the system. I looked in the questionnaires and the transcripts for evidence of how the participants referred to the system and how they interpreted the feedback the system gave them as they attempted to solve the riddles. Both sources of data reflect a large amount of uncertainty over what the audio and lighting feedback cues meant. On the questionnaire, in response to question 1.4 “Please describe in what respect you feel positively or negatively toward the system?”, participants responded: “Confusing, gets frustrating interpreting the feedback (light and sound)” and “I think the sound to indicate cold/warm could be more clear. The lights and ambient sound was unclear if its there for effect of purpose”. Darkness and a lack of sound was relatively easy to identify as the non-optimal state, but the meanings of the different colours of lights were much more ambiguous. The tutorial session used the convention of “hot, warm, cool, cold” to identify when the group was approaching the intended solution. In the gameplay session, some participants were able to map the hot/warm response on to the red lights and the cold/cool response onto the blue lights, but other people professed to be confused about what the colours meant. One participant said on the questionnaire that they enjoyed the responsiveness of the system, but still found it confusing: “Positive: the sound & light feedback; Negative: still can’t figure out what different light mean”. The fact that a red light typically signals “stop” or “danger” rather than “correct” may have been a factor in this confusion. Some people even suggested that the system response was simply random or intended to confuse. One participant wrote on the questionnaire that they “weren’t quite sure whether some of the sounds and lights were random or responding to movement”, and during a gameplay session another participant remarked “Yes, this machine is not very, not very developed, we're thinking.” Some of the groups reported a significant lag between the actions that they took and the response of the system, which caused problems in correlating the audio and lighting feedback with the actions that triggered them. This lag appears to have been perceptual, rather than system-side, but still caused confusion. A participant reported on the questionnaire “The slow response of the lights and sounds required us to slow down our actions and thinking. We had to wait for the system. It was unclear in some stages as to what the changes in light and sound signified." In the numerical scale questions, two in particular showed an even spread across the responses, as opposed to being weighted towards a positive response. Question 1.2 asked "Did the system require a large effort to learn?", with responses ranging from 1 = "very large" to 5 = "very little". As seen in Figure 19, the answers are spread across the range, reflecting the challenges faced in learning the feedback system.

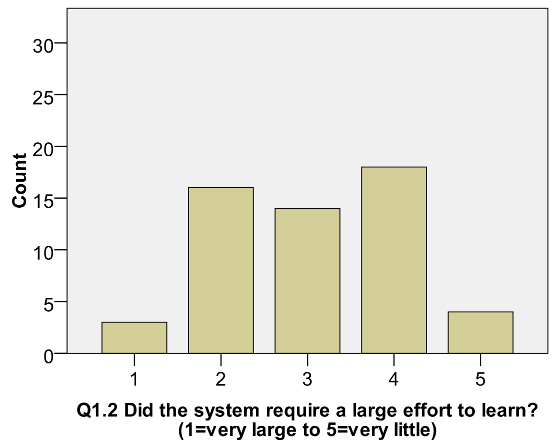


Figure 19. Socio-ec(h)o questionnaire response on learning

Similarly, question 3.1 asked "Do the lights and audio work together to help you in the game?", and Figure 20 shows the range of responses.

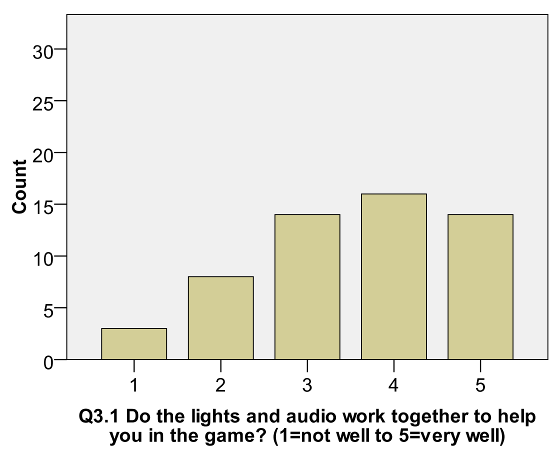


Figure 20. Socio-ec(h)o questionnaire response on helpfulness

The most salient feedback that the system gave was the audio completion noise, sometimes called the “audio reward”; some participants reported that they were really only paying attention to that noise and none of the other audio or lighting responses. One wrote: “To me the lights were a bit too random to help solving the puzzle. The background sound was a background music to me; it only helped me understand the puzzle better (but not always). The sound cue was more effective.” But other participants noted that sometimes the sound cues came too quickly; some of the solutions required that a specific position be held for a certain amount of time, and hearing the reward noise would cause the group to break formation and fail to complete the level. Each of the levels had background audio connected to the riddle content or theme of the level, but for most participants this was not seen as relevant compared to the explicit sound cues. As laid out in the system description above, the soundscape for each level varied, both in terms of audio content and the changes to the soundscape that signalled increased intensity as the group approached the goal state. The changing of the feedback mechanism for each level appears to have interfered with the ability to learn what the gradient feedback meant, decreasing its usefulness. Question 3.5 asked “How well does the virtual system integrate with the physical and architectural space?”, and Figure 21 shows a wide range of responses.

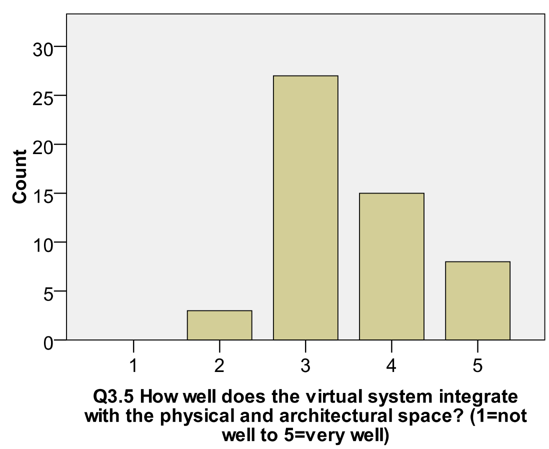


Figure 21. Socio-ec(h)o questionnaire response on integration

Despite the difficulties experienced in understanding the system feedback and figuring out the desired solution, other Likert-scale questionnaire results reflect that an overall positive experience was had by most of the participants (Figure 22).

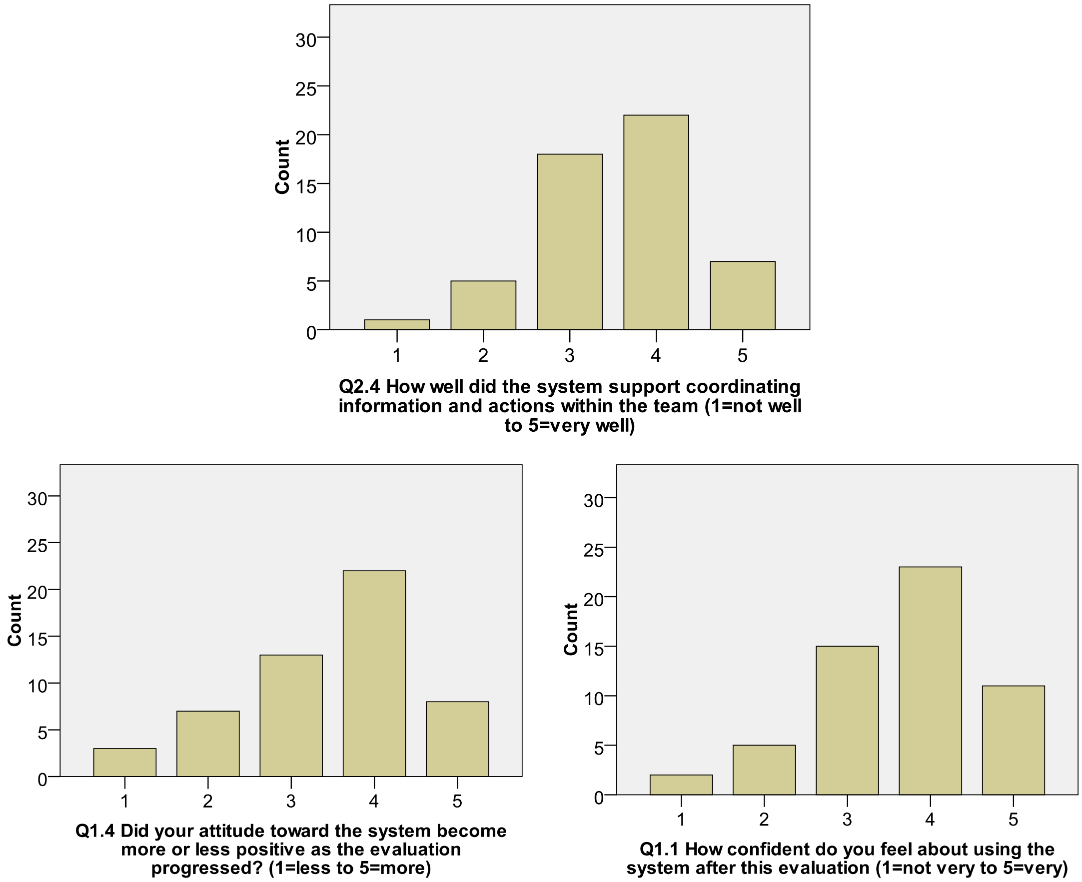


Figure 22. Socio-ec(h)o questionnaire responses on the system

The game was seen as challenging, and aspects of the experience frustrating, but it was a challenge most said they enjoyed tackling. In the gameplay sessions, groups would sometimes beg to be allowed more time to complete a level, even if they had previously been complaining about how confusing, frustrating and tiring it was. In this respect, the design intentions to allow for rich communication and interaction amongst the participants are fully supported. In the questionnaire short answers, the group teamwork aspect of the game is identified as one of the most positive aspects of the gameplay. While the participants also identified plenty of things that could be fixed to improve the system in the short answer sections, the numerical ratings for most questions on the questionnaire grouped towards the high end.

One final element that contributed to confusion over how to understand the system was the fact that there were occasionally crashes of the entire sensing and feedback systems. Unfortunately, these crashes were indistinguishable to the participants from the dark “no feedback” state, and they were not always noticed immediately by the researchers. It was only after several minutes of being unable to get any response from the system that the participants would begin to question whether something was wrong. This often led them to lose track of what they had been working on, and occasionally meant that correct or near-correct solutions were missed because they were tried and discarded during a time when the system was not functioning correctly. A crash early in the gameplay session could significantly undermine the trust in the system, and groups that experienced this would more frequently question whether the system was working correctly throughout the rest of the session, whenever they were having trouble getting a response. On the questionnaire, one participant remarked “It got frustrating because I wasn’t sure if the system didn’t properly track us (if we were doing it right), or if we were just doing it wrong.” Distinguishing the “dormant” state from the crashed/error state may have helped avoid this confusion.

6.4.2.3 Proposition 2 Summary

In examining the designer and participant perspectives on tangibility and adaptivity, the following key elements are seen:

Designers

- Intensity-based soundscapes rather than distinct cues for most audio feedback
- Coarse whole body tracking rather than more detailed tracking to allow for gesture based communication

Participants

- The audio and visual feedback was frequently confusing to the participants
- Questionnaire data reflects a generally positive experience, with some reported difficulties in learning the system, finding the feedback helpful, and seeing the connection between the virtual and physical space
- A lack of distinction between dormant and crash state lead to confusion and not trusting system functionality

6.4.3 Proposition 3: The Effect of Adaptivity

The final proposition under consideration is: In tangible or ubiquitous systems that utilize intelligent techniques to provide adaptive system responses, the designer’s intended adaptive effect differs significantly from the actual experience of the adaptive system by the users. Here I look at how the participants talked about the responsive system during gameplay and in the post-session questionnaire.

6.4.3.1 Designers: Open to Interpretation

As discussed previously, the goal of the designers was to create an aesthetically rich interaction within an augmented environment. The design of the system and instructions on how to interact with it was deliberately underdetermined, in order to prompt interpretations from the participants.

6.4.3.2 Participants: Seeking Guidance

Most conversations within the gameplay sessions revolved around musings on what the riddle meant and efforts to coordinate physical actions as a group. However, there were also some short discussions of the system as an entity. Several participants referred to the system as "wanting" or "desiring" some particular action from them, attributing a kind of theory of mind or emotional valence to the system. One participant encouraged his group members to move by saying "see it wants to activate, just keep moving..." In another session, a participant narrates an attempt to solve the puzzle as follows: "The light likes it..It liked that for a while but it didn't like it indefinitely....And it likes this too...it likes that too! It's close right? Stand up...and then back?...Move!...I don't know! It's not liking us so much anymore". Later, frustrated and confused by a long level, this same participant declares "I swear it liked it before...it's fickle". There was a natural instinct to interpret the system feedback as representative of the system's desires or emotions towards the group.

There were also frequent discussions of what the system might be capable of picking up or detecting. Many participants attempted some kind of arm movement or gesture as part of a solution at some point during game play, and then either realized on their own or were reminded by their fellow participants that the system would not be able to pick up on that level of movement. Aside from attempts to gesture, which seemed like an intuitive, pre-reflective action, most participants appeared to be very aware of the fact that the sensors on their backs were what the system was responding to. While discussing a solution involving rolling on the floor, participant remarks "cause we can't go down, we can't roll on the floor we'll cover up this thing", while other groups would arrange themselves with their backs all facing the same direction in an attempt to have the system pick their movement pattern up. Participants were less certain when speculating about how complex of a solution the system might be able to detect. One participant asserted that the system could only detect current location and proximity to other players, but not direction or movement, which was false. Others doubted whether the system would detect sequences of different actions, despite being told at the start of the session that some of the solutions involved multiple stages of coordinated actions. One participant speculated whether or not the system could understand sound and attempted to solve the Big Bang level with vocalisations: "Does it register sound and we don't know if it does? Bang!"

Question 2.3 asks “How well did the system respond when you were having problems solving a puzzle?” and the responses can be seen in Figure 23.

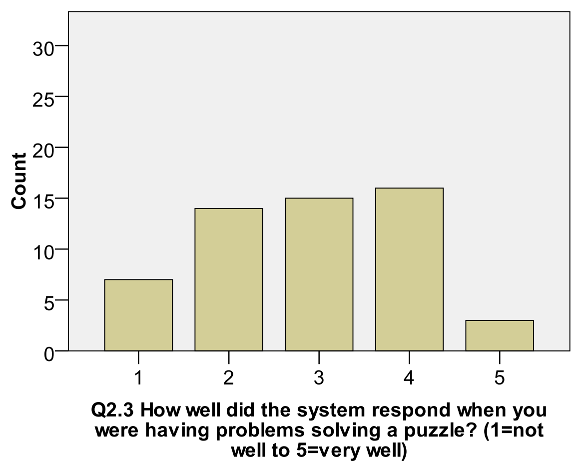


Figure 23. Socio-ec(h)o questionnaire response on responsiveness

This response gets at the final element that emerged when looking at the gameplay as a whole: that the feedback system could only really confirm that the players were doing something correctly. If they were completely off base, trying things well outside the solution set, there was no way for the system to guide them back to the correct path. While the blue/cold lights may have been intended to provide this kind of guidance, in practice they do not seem to have achieved this goal; most participants identified the darkness/absence of light as the negative state rather than the blue lights. For most participants, there was really only a binary set of states: darkness, which meant bad, and light, which meant good. This meant that groups could get quite frustrated exploring many non-productive paths before stumbling on the right one. In the questionnaire, question 2.2a asks “Can you describe how the system responded when you were having problems solving a puzzle?” and participants replied: “It didn’t. It became frustrating when stuck, and no “leads”. If we didn’t get it right away, it would take the whole time” and “The system has a good “you-are-cold-now” audio response, but no further clue is given for leading us towards the solution. We can get totally idling without knowing what to do.” This was seen also in some of the manual groups who had trouble with level 4; even though they were told exactly what the solution was, when they failed to complete it successfully they did not really know what had gone wrong.

6.4.3.3 Proposition 3 Summary

In examining the effect of adaptive components, the following key elements are seen:

Designers

- The designers wanted the experience to focus on aesthetic interaction and a feeling of discovery
- There was a deliberate underdetermination of the design and the instructions given to the players, to leave the experience open to interpretation

Participants

- The system was sometimes anthropomorphized as wanting or desiring
- Participants speculated on what the system could know about
- There was a lack of guidance towards the solution, with the the feedback being only hot or cold for what they are already doing

6.4.4 Socio-ec(h)o Discussion

From this analysis of the socio-ec(h)o data, there are two main concepts that I think are crucial for understanding how people interpret and respond to the ambiently intelligent system: *trust* and *guidance*.

6.4.4.1 Proposition 1

Figure 24 shows the starting conceptual framework updated for the designers’ understanding of the socio-ec(h)o system. The ubiquitous environment acts as an interface for the participants to explore solutions to the riddle, while the adaptive components provide feedback on reaching the goal state.

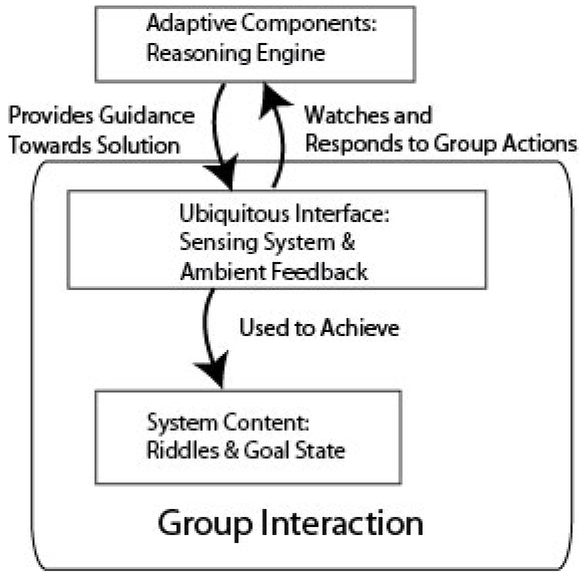


Figure 24. Designers' understanding of socio-ec(h)o

In Figure 25 the participants' experience of the system is depicted. For most participants, the central feature of the system was the work that had to be done to interpret the level riddles and the feedback from the ambient system.

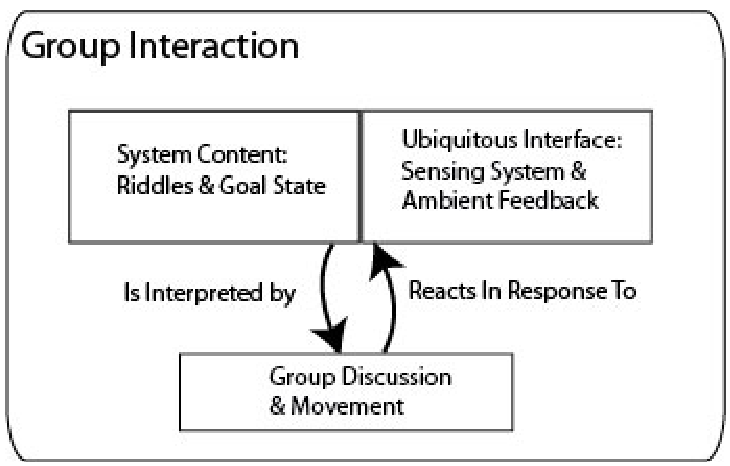


Figure 25. Participants' understanding of the socio-ec(h)o

The conversations within the space show that for most participants and levels, the interpretations given to the riddles were focused on literal interpretations. Only when they were frustrated with the level would the groups explore more esoteric possibilities. While the system allowed for creative interpretations, most groups stuck closely to a literal connection between the riddle's words and their movement patterns. It is possible that the novelty of the whole experience encouraged them to stick to more straightforward interpretation of the riddles; with more familiarity with the system, more creative and lateral riddles might be solvable.

6.4.4.2 Proposition 2

With relation to the physical environment, one key concept coming from the data is the notion of *trust*. In trying to find the solution for each level, the participants want to put their trust in the system, to rely on the fact that it is giving them reliable and consistent feedback. The perception of significant lag between action and response time made it difficult to correlate what actions were producing what responses, making the system seem inconsistent or random to some. The occasional crashes further undermined trust that the system was working as intended and led participants to question its functioning even when it was not crashing. The design intention to allow for free and interpretive goal reaching and explorative learning was undermined in places, such as by the tight parameters of level 4's solution and the showing of solution videos at the end of the levels. The inconsistency that this exposed, with level 4 being different from the others and with the solution videos sometimes being different from the configurations used by the groups, undermined trust in the overall system.

6.4.4.3 Proposition 3

The second concept that comes up, connected to adaptivity, is the notion of *guidance*. The primary way that participants talk about the system is in terms of what the system "wants" them to do or what it "likes". They know that the system is watching them, waiting for them to get it right, and giving them feedback on how close they are. But the audio and visual feedback is ambiguous and hard to interpret, leading to confusion and annoyance. Even for the groups who understand the feedback, there is frustration over the fact that simply categorizing their actions as "good" or "bad" does not give them the information they need to move towards the solution. The system is watching and judging them, but not helping. The consistently changing feedback mechanism for the audio soundscape contributes to this difficulty in perceiving guidance within the system responses.

7: Synthesis of Cases

In this final analysis chapter, I look at all the cases together and present a cross-case analysis comparing the different systems. I return to the original research questions and propositions set out at the start of the analysis and identify themes and concepts from the data that relate to them.

7.1 Proposition 1: Experience of Adaptivity

RQ1: What are the expected and actual benefits to the user experience that come from including adaptive components in ubiquitous and tangible systems?

P1: Designers have a greater belief in the benefits of adaptive components than the users experience.

In each of the three systems under study, the inclusion of adaptive components is intended to provide an enhanced user experience in some way. In the Reading Glove, the recommendation engine was supposed to provide guidance in navigating the non-linear story. For Kurio, the reasoning engine monitored and adjusted the flow of the group experience while also attempting to assign well-chosen challenges to each individual. Socio-ec(h)o's adaptive elements provided responsive feedback on the game state and proximity to the goal state. These are all common ways that adaptivity is used in current technological systems: to provide guidance or to optimize and personalize an experience in some way. In each of the three systems, there are elements of the adaptivity that were not experienced in quite the way that the designers expected. In this section, I use the concepts of *awareness* and *interpretation* to examine the basic experience of adaptivity.

7.1.1 Awareness and Interpretation

The first issue to consider when evaluating the experience of an adaptive system is the level to which the users are aware of the adaptivity and how they interpret the adaptive effects. Awareness of the adaptive components is not necessarily a prerequisite for a successful adaptive system; many of the visions of a ubiquitous and intelligent environment involve it monitoring inhabitants invisibly, supporting action within the space without being obvious about it. However, the realization of this maximally unobtrusive system is still some ways off, and until we reach that point, it is important to understand how people react to systems that are more of a presence. It may even be the case that unobtrusiveness is an unhelpful goal in these systems; Chalmers and Galani suggest that "seamful interweaving" of components is more desirable than a seamless experience (Chalmers and Galani, 2004).

In the Reading Glove analysis, I presented evidence that people were aware of the different forms of adaptivity they experienced, even if they were not quite conscious of that awareness. That is, people in the random condition of the study were more likely to report a poor experience while following the recommendations, whereas people in the intelligent conditions were more likely to say that they had trouble when they strayed from the recommendations. However, when talking about the possible intelligence underlying the system, many people felt that the system was more intelligent than it actually was, or that the adaptive component was affecting more aspects of the experience than it really was by changing the structure of the story or the fragments that could be accessed at any given time. Similarly, in socio-ec(h)o, the designers' intentions were to create an interpretative system that provided ambient feedback on group progress towards a specific goal state. In practice, many of the groups using the system experienced frustration and confusion over what the system "wanted" from them rather than interpreting the hot and cold ambient signals as a guidance system. Winograd and Flores advocate for approaching the design of HCI, particularly intelligent systems, as a conversation between the designer and the user (Winograd and Flores, 1986). In the case of socio-ec(h)o, this conversation analogy arose naturally for several of the participants, who (in a somewhat tongue-in-cheek fashion) attempted to talk to the system to find out what it wanted.

In both the Reading Glove and the socio-ec(h)o studies, participants readily built models of how the systems worked, coming up with different ways that the recommender might work or the story might be delivered in the Reading Glove case, and speculating on the feedback and response system of socio-ec(h)o. These various interpretations were often not quite in line with the designers' models, which could indicate that there is a need for a better cluing system to deactivate inappropriate assumptions. In socio-ec(h)o, the groups that were given a manual to use for the first levels of the game ended up using vocabulary and interpretations based on the language of the model, showing that people readily pick up on clues given to them. However, there is an argument to be made that when dealing with novel interaction paradigms in this way, there is some value in leaving the model relatively unspecified and seeing how people make sense of the system in the absence of explicit cues. We currently do not have a clear sense of the most useful model of the tangible interaction process (Djajadiningrat et al., 2007; Hurtienne and Israel, 2007). Many of the models proposed up to this point are top-down rather than bottom-up; that is, they are created by designers of tangible systems and represent a high level understanding of the design and construction of tangible systems (Klemmer et al., 2006; Hurtienne and Israel, 2007; Imaz and Benyon, 2007).

Notable exceptions to this trend include the work done by Svaneas and Verplank on metaphors arising naturally from playing with simple interactive tiles and by Williams et al. on understanding how people interact with the SignalPlay installation (Svanaes and Verplank, 2000; Williams et al., 2005). This dissertation takes a similar approach to generating an understanding of the models created by users and grounded in their experience of the system. In the Reading Glove data, I showed how users moved through stages of Orienting -> Exploring -> Re-Evaluating -> Wrapping Up in interacting with objects, and observed several different modes of approaching the physical objects, from deep engagement to disinterest. From the socio-ec(h)o system, there is rich data on how participants worked on interpreting each level's puzzles in terms of bodily movement, and how they tried to make sense of the feedback. This physical interrogation of the space and technology is in line with the embodied, "being-in-the-world" approach advocated by several current theorists (Dourish, 2001; Svanaes, 2001). Understanding the way users approach, construct, and test their models of novel systems will give us better insight into this embodied meaning-making happens, and how we can design adaptive systems that leverage this process.

The Kurio participants showed very little awareness of an adaptive affect at all, and they did not speculate at all about how the system functioned in terms of the challenge assignment. I believe this difference can be attributed to how much explicit training they received in how to use the system, plus the fact that researchers were on hand continually to help them when they were stuck or when something broke. They did not think much about how the system worked at a deeper level, because they did not have to do any active figuring out of the mechanisms underlying it; they just had to remember the steps they had been taught to follow. In Dourish's interpretation of Heidegger, this kind of deeper knowledge arises out of the cycle of experiencing technology as present-at-hand and ready-to-hand (Dourish, 2001). Kurio participants rarely experienced fluid, engaged use of the system (the ready-to-hand state) because of the frequent technical troubles; they also did not get to grapple with reflecting on and fixing the trouble (breakdown and the present-at-hand state) because the researchers took on that task. Thus they never really engaged with the system enough to make their own meanings around and with it. They also did not have sufficient opportunity to reflect over the correct and incorrect answers, which was a flaw in the design and may have encouraged a lack of reflection in general. A final factor that may have been at play here is that the participant pool for this study was drawn from the local public, rather than from the academic community, as was the case with the other two systems. The academic audience would have naturally been more critical and reflective about the technology they were using, since they were trained or in training to be technology designers themselves.

7.2 Proposition 2: Adaptivity within Tangible and Ubiquitous Computing

RQ2: How do the adaptive components support or complicate the ubiquitous and tangible system elements?

P2: Designers believe that adaptive components can increase the ease of use or enhance learning or other experiential elements of ubiquitous systems, but in fact the adaptive components are more likely to add hidden complications.

This collective case study is focused on a set of systems that are not only adaptive but also deploy tangible and ubiquitous computing elements to create a unique experience. In the Reading Glove, a wearable RFID reader and tagged objects created a physical story world that could be picked up and manipulated. For Kurio, a wide range of elements, from tangible tools to tabletop displays to a distributed sensor system created a layer of additional information for the museum. Socio-ec(h)o used ambient sensing and audio/visual feedback to create a unique environment supporting whole-body play and exploration. The combination of novel interaction design, prototype technology, and adaptive technology is one that holds great promise for creating engaging and innovative experiences, but also contains the potential to go astray very easily if one of the elements is out of balance. In exploring how the adaptive and tangible/ubiquitous elements interact, the concepts that arose were *complexity* and *collapse,* and *augmentation* and *legibility*.

7.2.1 Complexity and Collapse

When examining the user experience of adaptive, tangible and ubiquitous systems, the first thing that leaps out is the way in which users of such systems collapse the adaptive and tangible elements together into one big, complex system. Each of the conceptual frameworks presented in the individual case analysis chapters detail how the designers' view of the system differs from the participants' view. From the perspective of the designers of the Reading Glove, it seemed clear that the adaptivity was located solely in the recommendation system, but for the participants using the system, the boundary between that element and the story delivery mechanism was not obvious. Many participants appeared to believe that there was an adaptive or dynamic component that determined what story clip to play next when an object was selected, when in fact each object only had two lexia that flipped back and forth. During the design phase, there had been concerns that people would figure out the system too easily if the clips flipped back and forth regularly, but clearly this was not the case.

Similarly, data from the Kurio system shows that using the tangible and ubiquitous elements are much more salient than reflection on how the system works or what might be underlying the challenge assignment and game flow aspects. The questions at the end of each challenge, which were intended to update the model with regard to how difficult the challenge was for the individual to complete, were interpreted by some as being related to the functionality of the tangible tools and sensors. Finding ways to present complex technological systems in comprehensible and usable ways is a real challenge for the field of adaptive and tangible/ubiquitous design, since evidence suggests that multiple novel aspects collapse into each from the users' perspective, complicating the learning process.

7.2.2 Augmentation and Legibility

Grappling with this complexity is a worthwhile endeavour, however, as seen in the ways in which tangible and ubiquitous components add surprising and innovative elements to the user experience. Using the Reading Glove to interact physically with a non-linear narrative provided a rich and engaging way to experience a story. In Kurio, the use of tangible tools to activate museum artifacts via sensors provided a sense of interaction that is not normally possible with objects protected behind glass. This augmentation of physical objects and spaces in playful and educational ways holds great potential for engaging interactive systems. Similarly, in socio-echo, participants showed an awareness of the sensors on their backs that changed the way they interpreted both the environment and their actions within it. They discussed the fact that the system would not be able to see arm movements, or that rolling on the floor might damage the sensors. This shaping of meaning-making by technology is a key component of newer theories of embodied interaction and intelligence (Clark, 1996; Agre, 1997; Dourish, 2001). The augmentation of their bodies with the sensors changed their understanding of their own form as well as how their actions and motions were recognized by the space.

Related to this notion of augmentation is the idea of legibility. In order to add a layer of interaction to the museum objects, current technology requires the addition of a sensor or tag. The legibility of this augmentation changes the interpretation of the museum space, signalling where the game is being played and constricting the number of artifacts that can be considered as viable interactive objects. On the flip side, the illegibility of the feedback mechanism in socio-ec(h)o gave rise to confusion and frustration on the part of the interactors. The audio and lighting cues were hard for many participants to interpret, and the fact that the crash state and the dormant state could be confused for each other led to “misreading” of the system state. Benford et al. describe the “expected, sensed, desired” framework as one way of thinking about these issues across different interfaces and environments (Benford et al., 2005). The framework provides a way to explore what users might do within the system and what responses those actions can have, making both user action and system response more legible.

7.3 Proposition 3: The Effect of Adaptivity

RQ3: How do the goals and intentions of the designers of adaptive and ubiquitous systems compare to the actual experience that users have of the designed system?

P3: In tangible or ubiquitous systems that utilize intelligent techniques to provide adaptive system responses, the designer’s intended adaptive effect differs significantly from the actual experience of the adaptive system by the users.

In the discussion of proposition 1 above, I looked at some of the ways that the designers' intentions for an adaptive effect did not match the experience of the participants. For proposition 2, I explored how the introduction of tangible and ubiquitous computing elements complicates the experience and interpretation of adaptive systems. Here, I deepen both of these ideas by examining in more detail how the introduction of adaptivity affects a user's ability to *control* and make *choices* within a novel system.

7.3.1 Trust and Surprise

It is human nature for people to relate to systems as if they are human, or at least have human elements. We easily and naturally speak of our computers have feelings, desires, and idiosyncratic behaviours, such as when a person says the computer is "having a bad day" or "hating me right now" when it is not behaving as expected. In the cases studied here, there were several places where anthropomorphic reactions to the system were in evidence, particularly in the greater and lesser amounts of trust expressed in the system. In the Reading Glove, readers claimed to trust the recommendation system to lead them on the correct path, even to the point of going against their own desires to choose objects other than the ones recommended. In socio-ec(h)o, there was a lack of trust on the part of the participants following system malfunction, leading them to question system behaviour that was accepted as normal prior to the breakdown. Winograd's Language Action Perspective theory uses trust as one of the key factors in establishing a dialogue between designer and user, allowing the user to take action with the system (Winograd, 2006).

Another example of more emotional and human-like reactions to the systems is the element of *surprise* attributed to the interactions with the Kurio system. The challenge assignments created positive feelings of surprise, which is an interesting emotion that has not been explored thoroughly in the design of adaptive systems. Typically an adaptive system is designed to be unobtrusive or to cater to an individual's specific preferences. Being surprised by a system's behaviour in a positive way is in some respects the opposite of this design goal, but possibly a pathway to deeper engagement and connection between system and user.

7.3.2 Control and Choice

In the Reading Glove system, in addition to a complicated relationship with controlling the system, the recommender also had an effect on the feeling of choice within the story. The relationship between feeling a sense of control, getting to choose, and engaging in an act of creation is clearly complex, and the ways the technological system of the Reading Glove mediates those feelings are hard to untangle. The adaptive element provided helpful guidance, but also impacted the sense of choice, lessening some of the agency that was felt by the participants.

In socio-ec(h)o, control was also a factor in the participants' discussions, but in a slightly different fashion. Much of the discussion of the system revolves around the feedback that is being given in response to the participant's movements in the space. The Reading Glove invites the participant to explore a story and assemble it for themselves; the primary control they have is how the story comes together in their mind. In socio-ec(h)o, by contrast, the participants are trying to match their actions to something that the system expects from them. The control mechanisms are underspecified, however, leaving them in a position of needing to figure it out on their own. This ties into the issues of guidance discussed previously. The Reading Glove had, in essence, no right answer. There was nothing that participants had to do in order to succeed at using the system, although they might come away with widely varying understandings of the story. The intelligent component was intended to guide them through the story, but could be ignored at any time. The socio-ec(h)o system had a goal state that had to be reached in order to complete or succeed at a level. The intelligent component was not just an optional guidance system; if the participants could not interpret the feedback, they were unlikely to reach the completion state. Thus the guidance was non-optional and when it failed, it was a significant problem.

In the Reading Glove analysis in Chapter 4, I looked at how reader choices can lead to two different types of control, one experienced frequently and the other more rarely. Crucially, I suggest that each of these forms of control is influenced differently by the presence of the adaptive recommendations. Control 1, which is expressed by making choices between the objects, can be hindered by the recommender. Some participants reported being afraid to deviate from the recommended objects, even when they would have preferred to make a different choice. The set of recommended objects constrains the participant's choices, limiting their options. Control 2, on the other hand, is connected to making meaningful choices in the sense of knowing what story fragment will be accessed by selecting a specific object. This sense of control was much harder to achieve, and the recommendation system was more helpful in promoting this form of control. This relationship is shown in Figure 26.

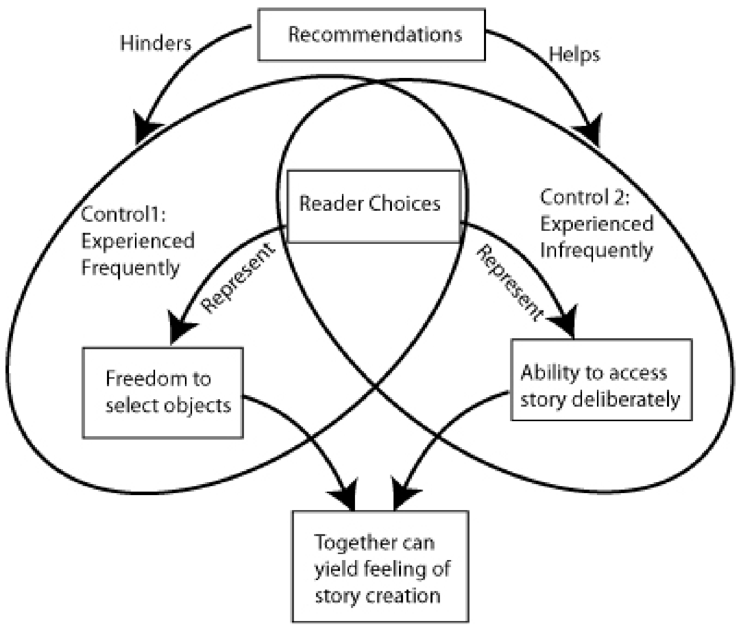


Figure 26. Participant's experience of choice, control and creation

As mentioned earlier in this chapter, the Kurio system differed from the other two in the amount of technical explanation and assistance given to the participants. Kurio was also much more technically complex than the other two systems, involving the use of tangible tools, a PDA, a tabletop display, distributed sensors, and a game structure. This complexity and the constant training or assistance from the research staff as a result of glitches and technical faults may have short-cut actual mastery of the system. As Djajadiningrat et al. discuss, mastery of new interactions can be a compelling and worthwhile experience, but they require effort (Djajadiningrat et al., 2007). Socio-ec(h)o and the Reading Glove both required active interrogation of the system to learn how to control it, while Kurio did not demand that level of reflection.

One element of control that was present in socio-ec(h)o and Kurio but not the Reading Glove was the use of socially negotiated control arising from group dynamics. Successfully using socio-ec(h)o required control over the other participants in the game as much as mastery of the system itself; a group that was uncoordinated or lacked leadership would struggle to complete the complex puzzles. Similarly, families using the

Kurio system had to negotiate the flow of the game around the PDA device when multiple people need to check on and complete their challenges. In the Reading Glove analysis, the notion of control was also closely tied into the idea of choice. In Kurio, there was an interesting aspect to choice that came up with regard to the time map that laid out the different missions making up the game. Families would choose 3 of the 5 missions to complete, and the map would automatically “fill in” the non-chosen missions. Several participants expressed dismay at this design decision, and it seemed as if the visibility of a choice not taken was somehow an annoyance or a negative factor. Like in the Reading Glove, there is an interesting tension between the desire to have choices and the desire to not “miss” anything in the paths that are not chosen. Although the goals of adaptive systems are typically to facilitate a user’s ability to make choices and control their experiences, it is clear from this collective case study that adaptive components complicate the experience of control and choice within complex technical systems.

7.4 Design Considerations

As a final contribution, I set forth design considerations in form of questions based on the concepts developed in this analysis. These questions are meant to help designers of adaptive and tangible and ubiquitous systems think about the way their systems will be experienced. They can be asked during the design process, and also used to structure the study of novel systems to investigate user experience.

7.4.1 Awareness and Interpretation

Users of novel system have a powerful drive to interpret the actions of the system and try to make sense of them. Although they do not always have a conscious awareness of the adaptive or intelligent components, they are capable of picking up on subtle design elements and distinctions. Some questions to ask related to this include:

- What aspects of the system are open to interpretation, and which will cause the most problems if interpreted incorrectly?
- What do users need to be consciously aware of, and what can they approach more intuitively?
- What stages do users move through in coming to terms with the system, and how can you facilitate that process?

7.4.2 Complexity and Collapse

In a complex system, users will conflate and collapse together elements that seem distinct from the designer's perspective. When designing such a system, ask:

- What elements do users need to be able to distinguish from each other?
- What happens if they merge them together?
- How can you cue important distinctions without making the system appear too complicated?

7.4.3 Augmentation and Legibility

Adding technology to a physical space or body can fundamentally change how people interact with it. When planning the application of tangible and ubiquitous technology, considering the following questions:

- How might the addition of a layer of technology to a space change the perception of that environment?
- How might sensors and tools change the user's conception of themselves and their capabilities?
- What needs to be legible to the user and what can be obscured?

7.4.4 Trust and Surprise

Intelligent components lead to more expectations of human-like behaviour, and a feeling of connecting with the system. When a system fails to live up to those expectations, trust can be lost. An intelligent, complex system will often surprise its users in good and bad ways, and sometimes its designers as well. These questions can help designers think about this more elusive, emotional aspect of interacting with intelligent systems:

- What elements most require that the user trust the system is functioning properly? How robust can you make them?
- How can you clearly signal when an element is not working versus simply dormant?
- Where can a feeling of surprise enhance the experience instead of detract from it?

7.4.5 Control and Choice

Adaptive systems hold the dual promise of giving people less control (such as by automating tasks) and more (by affording personalization and customization). Similarly, they can offer fewer choices (by making those choices automatically on behalf of the user) and more (by presenting at times endless options to select from). Striking the right balance between control and choice may be one of the most delicate parts of the design process, prompting the following questions:

- What does the system control and what does the user? How easily can that balance be adjusted by the user?
- What are the crucial choices to be made by the user? What can be made automatically by the system?
- Does making the choice visible to the user increase or decrease their feeling of control?

8: Conclusion

My research addresses a gap in the field of adaptivity for ubiquitous systems by taking a critical look at the notion of “adaptivity” and how users experience it. Through a set of detailed case studies of several different systems, I have developed a set of concepts related to the experience of adaptivity. These concepts are supplemented by a set of related design considerations that can assist in designers in thinking about key issues related to the concepts. My work is a first take on untangling the complex relationship between ubiquity, adaptivity and the design of novel systems.

Through this collective case study, I have examined the differences between the intended and actual experience of three adaptive systems. First I looked at the Reading Glove, an interactive storytelling system involving a piece of wearable technology that allowed participants to trigger story information by picking up objects. An adaptive component guided the reader through the story by recommending objects to interact with next. Next I examined Kurio, a museum guide system that involved playing an educational game distributed across a set of handheld and tabletop devices. The adaptive component attempted to gauge the appropriate learning level in assigning tasks to each individual. Finally, I spent some time with socio-ec(h)o, a group game played in an ambient environment, where teams of players had to coordinate their physical movements to solve riddle-based levels. Characteristics of the group’s movement, location and position were used to adapt the system’s ambient feedback system.

For each of these projects, I collected data on the design process and user studies conducted using the system. Transcripts of interviews with and discussions between the study participants provided the core data that was analyzed, with design documents, videos of the study sessions, surveys and system logs contributing additional context and support for the conclusions drawn. Each project was analyzed as a separate case and then the results of these individual case studies were combined in a cross-case analysis. The research questions that guided the case analysis were as follows:

1. What are the expected and actual benefits to the user experience that come from including adaptive components in ubiquitous and tangible systems?

2. How do the adaptive components support or complicate the ubiquitous and tangible system elements?

3. How do the goals and intentions of the designers of adaptive and ubiquitous systems compare to the actual experience that users have of the designed system?

Related to each research question was a proposition; data from each case was used to refute or support the claims made by the proposition:

P1. Designers have a greater belief in the benefits of adaptive components than the users experience.

P2. Designers believe that adaptive components can increase the ease of use or enhance learning or other experiential elements of ubiquitous systems, but in fact the adaptive components are more likely to add hidden complications.

P3. In tangible or ubiquitous systems that utilize intelligent techniques to provide adaptive system responses, the designer's intended adaptive effect differs significantly from the actual experience of the adaptive system by the users.

The results of this proposition-focused analysis highlighted the complexity involved in designing adaptive components computing systems making use of tangible and other novel interface styles. The experience of adaptivity within these kinds of systems is impacted by the user’s awareness of adaptivity and the interpretation of the adaptive effects. Factors like trust, surprise, augmentation, and legibility also play a role in grappling with intelligent components within complex systems. I showed that tangible and ubiquitous elements in complex adaptive systems are subject to collapse and confusion but still show great potential for creating engaging experiences. In the analysis of the user study data, the interconnected notions of control and choice came to the forefront, and I have attempted to unpack the complex relationships between these two concepts and the experience of using the system.

The final outcome of this analysis is a set of questions related to these concepts which can be used to guide design work in the area of adaptive, tangible and ubiquitous systems (Table 11). There is still enormous potential for future work in adaptivity, related to helping people make sense of novel interactions and grapple with new paradigms. With regard to tangible and ubiquitous computing, I suggest a need for more detailed study of the experience of using these systems, to learn how people learn new interaction methods. There is still a large area to explore with regard to how people come to terms with tangible and ubiquitous computing systems, particularly in leisure or entertainment focused domains, and I hope this dissertation is received as a first step to tackling the complexity inherent in this task.

Table 11. Design concepts and considerations

Awareness and Interpretation	• What aspects of the system are open to interpretation, and which will cause the most problems if interpreted incorrectly? • What do users need to be consciously aware of, and what can they approach more intuitively? • What stages do users move through in coming to terms with the system, and how can you facilitate that process?
Complexity and Collapse	• What elements do users need to be able to distinguish from each other? • What happens if they merge them together? • How can you cue important distinctions without making the system appear too complicated?
Augmentation and Legibility	• How might the addition of a layer of technology to a space change the perception of that environment? • How might sensors and tools change the user's conception of themselves and their capabilities? • What needs to be legible to the user and what can be obscured?
Trust and Surprise	• What elements most require that the user trust the system is functioning properly? How robust can you make them? • How can you clearly signal when an element is not working versus simply dormant? • Where can a feeling of surprise enhance the experience instead of detract from it?
Control and Choice	• What does the system control and what does the user? How easily can that balance be adjusted by the user? • What are the crucial choices to be made by the user? What can be made automatically by the system? • Does making the choice visible to the user increase or decrease their feeling of control?

Appendices

Appendix A: Reading Glove Study Protocol

Reading Glove Study Pre-Questionnaire

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

Basic Demographics

Age: ________ Gender: Male — Female

What program are you in? BA – MA/MSc — PhD — Other:______________

What department are you in? ____

What is your level of English language proficiency? (circle one)

Native Speaker – Fluent – Advanced – Intermediate – Basic

If English is not your first language, please indicate your native language:

____

Technology Use

What is your comfort level with computers?

Not At All Comfortable – Somewhat Comfortable – Pretty Comfortable – Very Comfortable

How much time do you spend on a computer each day, on average?

No Time – 0-2 hours – 2-4 hours – 4-6 hours – 6-8 hours – 8+ hours

At what age did you start using a computer? (approximately) ________

What is your comfort level with gaming systems (Xbox, Nintendo DS, Playstation, Wii, etc)?

Not At All Comfortable – Somewhat Comfortable – Pretty Comfortable – Very Comfortable

How much time do you spend gaming each day, on average?

No Time – 0-2 hours – 2-4 hours – 4-6 hours – 6-8 hours – 8+ hours

At what age did you start playing games on consoles or computers? (approximately) ________

Do you consider yourself a gamer? Yes — No

If yes, what are 5 games that you enjoy?________________________

____

Do you consider yourself a reader?   Yes — No

If yes, what are 5 books that you enjoy?________________________________

____

Have you ever used a tabletop computing system before?

Never – Once or Twice – Occasionally – Frequently

Have you ever used a wearable computing system before?

Never – Once or Twice – Occasionally – Frequently

Have you ever been involved in the development of a novel computing system or interface?

Never – Once or Twice – Occasionally – Frequently

If yes, please briefly describe your design experience:_____________________

____

____

When it comes to buying and using new technologies for personal use, are you most likely to:

a) Be one of the first people you know to start using a new technology (such as the iPhone, Skype, 3D television, etc)

b) Wait until a few friends or colleagues get something new and tell you about their experience before buying or using it.

c) Wait until almost everyone you know has the new technology before getting it yourself.

d) Have no interest in acquiring new technology.

Reading Glove Study Post-Questionnaire

Please rate the following statements according to how much you agree with them (place an X or checkmark in the appropriate box):

	Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree	No answer
The system was easy to use						
The actions I took didn't influence the story						
I would not be interested in experiencing another story like this						
The system was enjoyable to use						
My actions changed the story						
The system was hard to use						
The system was confusing to use						
I would like to experience another story this way						

Do you have any other comments or feedback on the system or this study?

Reading Glove Study Interview Questions

Ask each of the following questions, allowing time for the participant to think about the question and answer fully. If the participant gives an unclear or particularly interesting answer, ask followup questions for clarification.

Researcher: Now we're going to have a short interview about the story you just heard. We're interested in hearing about your impressions and experience of using the system, because this will help us learn how to design these kinds of systems. This isn't a test, so you don't have to work about getting things right or wrong. Just tell me what you remember as best you can, or what you thought about different aspects of the experience. We're interested it both positive and negative feedback.

1. What did you like about experiencing this story using the Reading Glove?
2. What did you not like about experiencing this story using the Reading Glove?
3. How do you think the system you just used worked?
4. What did you think was going on with the pictures of the objects on the screen?
5. How did you decide which object to pick up next?
6. If you had to describe how you use the system to someone else, how would you describe it?
7. Does using this system seem similar to any other activity or interaction?
8. What parts of your interaction do you think the system responded to?
9. Did you feel like the story changed based on your actions? In what ways?
10. Did you feel like the display of the objects pictures changed based on your actions? In what ways?

Researcher: Now I'm going to ask some questions about the story. Again, this information helps us understand how you experienced the Reading Glove, so that we can improve our work. Any impressions or thoughts you have on it are interesting to us.

1. Can you tell me what the story you just heard was about? What specific events occurred in the story? What characters do you recall?
2. What do you think might happen next in the story?
3. *Hold up the goggles:* What do you know about this object?
4. *Hold up the vase:* What do you know about this object?
5. *Hold up the camera:* What do you know about this object?
6. Can you tell me where the story took place? How do you know?
7. Could you tell what time period it took place in? How do you know?
8. What elements of the story were confusing?
9. How did you decide when you were done interacting with the objects?
10. How did being able to touch the objects affect your experience?
11. How does experiencing the story this way compare to reading a book?
12. How does experiencing the story this way compare to playing a game?

Appendix B: Kurio Study Protocol

Kurio Evaluation Protocol

updated July 30, 2008
Total Time: approximately 120 minutes

1. Preparation

1. Have package for each parent ready:
   - 1 ethics form (Be sure to number the forms with the participant numbers & name)
   - 1 media release form (Be sure to number the forms with the participant numbers & name)
   - 1 acknowledgment of receipt of certificates form
   - 1 pre-session 13+ questionnaire & pens (Be sure to number the forms with the participant numbers ONLY)
   - 1 post-session 13+ questionnaire & pens (Be sure to number the forms with the participant numbers ONLY)
   - Movie Certificates
2. Have package for each 13 yr. old and up ready:
   - 1 ethics minor form (Be sure to number the forms with the participant numbers & name)
   - 1 pre-session 13+ questionnaire & pens (Be sure to number the forms with the participant numbers ONLY)
   - 1 post-session 13+ questionnaire & pens (Be sure to number the forms with the participant numbers ONLY)
3. Have package for each 8 yr. old and up ready:
   - 1 ethics minor form (Be sure to number the forms with the participant numbers & name)
   - 1 pre-session 8+ questionnaire & pens (Be sure to number the forms with the participant numbers ONLY)
   - 1 post-session 8+ questionnaire & pens (Be sure to number the forms with the participant numbers ONLY)
   - stickers
4. Ready the wireless microphones
5. Ready the audio recorder.
6. Prepare video documentation
   - I video recorder will be handheld
   - 1 video recorder is on a tripod recording table activity
   - LABEL the video tapes!

2. Meet participants: (10 minutes) – Multi-purpose room

1. Introduce everyone involved in the evaluation
2. Provide an overview of the evaluation session. STATE THAT THEY CAN STOP AT ANYTIME.
3. Provide ethics and media release forms for signature (Be sure to witness the forms – anyone of us can do that).
4. Explain that we will be videotaping and recording. Put on the microphones and start recording.

Audio Documentation: Turn on the microphones

5. Ask preliminary questions (see sheet)
6. Ask participants to fill out the pre-session questionnaires.

Audio Documentation: Turn off the microphones

3. Introduction and tutorial (15 minutes) - Exhibition

Introduce the different parts of Kurio and give a tutorial.

4. Kurio Interaction (30-45 minutes) - Exhibition

Audio Documentation: Turn on the microphones

Video documentation: turn on the handheld and stationary video recorders

Allow families to interact with Kurio. Document in an unobtrusive manner as possible by video.

Audio Documentation: Turn off the microphones

Video documentation: turn off the handheld and stationary video recorders

5. Post-Session Questionnaire and Interviews (20 minutes) – Multi-purpose room

1. Let participants have a short break, go to the bathroom etc. as needed.
2. Distribute the questionnaires and be in the room to help them complete the questionnaires, especially the children. Try to keep it fun and not too seriously.

Audio Documentation: Turn on the microphones

3. Conduct a group interview using the post-session semi-structured questions.

Audio Documentation: Turn off the microphones

6. Instructions for Follow-up Interview (5 minutes)

Show them the package for the self-conducted follow-up interview. Explain how to conduct and record the interview as well as mail them back.

Thank them for participating!

Kurio Interview Questions

updated July 30, 2008

Pre-session questions:

1) Have you ever visited the Surrey Museum? How often do you go to museums? What is your favorite museum? What makes it your favorite?

2) What do you like about museums and what do you not like about museums?

3) Do you have a connection to Surrey? What do you know about Surrey's past? Are you interested in learning more? Is there anything in particular you might want to learn about?

Post-session questions:

1) What are things that you found interesting in this visit that you would tell a friend about?
2) Did you like this visit? What are some positive and negative things about this visit?
3) Did you feel you learnt more about Surrey? If so, what did this visit make you think the most about?
4) What parts of using Kurio fit well with you and your family?
5) What parts do not fit well with you and your family?
6) What parts of Kurio were fun and what parts were frustrating?
7) Any other comments?

Pre-Session Questionnaire 8+

Kurio pre-session - questionnaire

Participant # ____
You can skip any question you like! Ask for help too!

Part One:
A. Have you been to the Surrey Museum before? (circle one)
Yes **No**

B. Do you like going to museums? (circle one)

Yes **Sometimes** **No**

Part Two:
H. How often do you use these?

	A lot	Sometimes	Never	Huh? What is this?
Computer				
Video games like XBOX 360, XBOX, PlayStation 2 or 3, Wii, GameCube				
Portable games like Nintendo DS, PSP, GameBoy				
Cell phone				
PDA like a Blackberry, iPhone, Palm				
Other stuff				

Pre-Session Questionnaire 13+

Participant # ____

Please ask if you have any questions about completing this questionnaire.

Section A

A.1. Have you visited the Surrey Museum before?

Yes	No

A.2. If you answered yes above, how many times have you visited the museum?

1	2	3	4	5+	10+

A.3. How many times a year do you visit museums?

1	2	3	4	5+

A.4. On average, do you visit museums with your family?

Yes	No

A.4. Rank the statements below as they apply to you from 1-6 (1 is the highest)

	I visit museums for entertainment
	I visit museums to learn
	I visit museums for a family activity
	I visit museums with friends as a social activity
	I visit museums for other reasons
	I do not visit museums

Section B

B1. Rate your use of the following computer and electronic devices

Often	Sometimes	Never	
			Personal computer
			PDA/Handheld
			Cell phone
			Video console
			Portable game device
			Other

Post-Session Questionnaire 8+

Kurio post-session – questionnaire

Participant # ____

You can skip any question you like! Ask for help too!

Part One: Smileyometer

A. Did you have fun with Kurio? (circle one)

B. Was Kurio easy or hard to use? (circle one)

C. Were the tasks given by Kurio easy or hard? (circle one)

D. Were you excited or bored about the next task given to you by Kurio? (circle one)

E. Was Kurio helpful in learning about things in the museum? (circle one)

F. Was Kurio fun to use with your family? (circle one)

G. Is using Kurio a good way to visit a museum? (circle one)

You finished part one! Now you can continue to part two!

Part Two: Fun Sorter

F. Stick the pictures where you think they belong. Use only the stickers of Kurio parts you used. You can stick more than one picture in a box.

	Best			**Worst**
Part of Kurio that was the most fun				

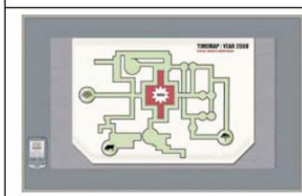
G. Stick the pictures where you think they belong. Use only the stickers of Kurio parts you used. You can stick more than one picture in a box.

	Best			**Worst**
Part of Kurio that was easiest to use				

You finished part two! Now you can continue to the last part!

Part Three: Again – Again
What things would you like to do again?

H. Would you like to use these parts of Kurio again?

	Yes	Maybe	No	I did not use this
 Finder				
 Listener				
 Pointer				
 Reader				
 **Table**				
 **Monitor**				

H. Would you like to explore these parts of the time map again?

	Yes	**Maybe**	**No**	**I did not explore this**
 Aboriginals				
 Tradesman				
 Farming				
 Forestry				
 **Home Life**				

You are all done!
Thanks for helping us!

Post-Session Questionnaire 13+

Kurio evaluation– questionnaire

Participant # ____

In the questions below, we ask you to rate an answer along a scale of 1-5 or circle "No opinion," if you cannot rate an answer. Some questions we ask you to provide written answers. If the space provided is not sufficient please use the back of the sheet. Please ask if you have any questions about completing this questionnaire.

Section A

A.1. How much fun was Kurio (circle one)?

(not very)	no opinion	1	2	3	4	5	(very)

A.2. How confident do you feel about using Kurio after the evaluation (circle one)?

(not very)	no opinion	1	2	3	4	5	(very)

A.3. Did Kurio require a large effort to learn (circle one)?

(very large)	no opinion	1	2	3	4	5	(very little)

A.4. Did your attitude toward Kurio become more or less positive as the evaluation progressed (circle one)?

(less)	no opinion	1	2	3	4	5	(more)

A.4a Please describe in what ways you feel positively or negatively toward Kurio?

Section B

B.1 How well did Kurio help you in exploring the museum in ways that interested you (circle one)?

(not well)	no opinion	1	2	3	4	5	(very well)

B.2 How well did Kurio let you enjoy the museum with your family and or friends (circle one)?

(not well)	no opinion	1	2	3	4	5	(very well)

B.3 How well did Kurio help you learn about the museum exhibition and the artefacts (circle one)?

(not well)	no opinion	1	2	3	4	5	(very well)

B.4 How well did Kurio let you learn together with your family and or friends about the museum exhibition and the artifacts (circle one)?

(not well)	no opinion	1	2	3	4	5	(very well)

Section C

C.1 How well does Kurio fit in with the exhibition environment (circle one)?

(not well)	no opinion	1	2	3	4	5	(very well)

C.2 How integral a part did Kurio feel with the exhibition (circle one)?

(not very)	no opinion	1	2	3	4	5	(very)

C.3 Did using an interactive system like Kurio benefit your experience of the museum exhibition (circle one)?

(not very)	no opinion	1	2	3	4	5	(very)

C.4 How well does an interactive system like Kurio fit with how your family would like to visit museums similar to the Surrey Museum (circle one)?

(not very)	no opinion	1	2	3	4	5	(very)

C.4a Can you describe the characteristics of Kurio that fit well with you and your family?

C.4b Can you describe the characteristics of Kurio that do not fit well with you and your family?

C.5 If you were the monitor (used the PDA), how much do you feel you helped others in exploring the museum (circle one)?

(not very)	no opinion	1	2	3	4	5	(very)

C.5a Can you describe some aspects of how you helped or had trouble helping others?

Section D

D.1 Is using Kurio a good way to visit the museum (circle one)?

(not good)	no opinion	1	2	3	4	5	(very good)

D.2 How easy was Kurio to use (circle one)?

(not easy)	no opinion	1	2	3	4	5	(very easy)

D.3 Were the tasks Kurio assigned helpful in exploring and learning in the museum (circle one)?

(not well)	no opinion	1	2	3	4	5	(very well)

D.3a What parts of Kurio were not helpful or frustrating?

D.4 How interested were you to get the next task assigned (circle one)?

(not interested)	no opinion	1	2	3	4	5	(very interested)

D.5 If you or a member of the family completed a task successfully, how difficult was the next task (circle one)?

(too difficult)	no opinion	1	2	3	4	5	(appropriate)

D.6 If you or a member of the family <u>did not</u> complete a task successfully, how difficult was the next task (circle one)?

(too difficult)	no opinion	1	2	3	4	5	(appropriate)

D.7 What functions in Kurio were missing or what would you change?

Section E

E.1 How much did you discover that you did not know previously (circle one)?

(not much)	no opinion	1	2	3	4	5	(very much)

E.2 How much more did you learn about things you already knew (circle one)?

(not much)	no opinion	1	2	3	4	5	(very much)

E.3 How much more curious did the museum experience make you (circle one)?

(not curious)	no opinion	1	2	3	4	5	(very curious)

E.4 How exciting was it to learn (circle one)?

(not exciting)	no opinion	1	2	3	4	5	(exciting)

E.5 Some of what I learned will be useful to me (circle one)?

(not useful)	no opinion	1	2	3	4	5	(very useful)

Section F

F.1 Any additional comments?

Thank you for completing this questionnaire and participating in our research!

Appendix C: Socio-ec(h)o Study Protocol

Socio-ec(h)o Evaluation Protocol

Total Time: approximately 140 minutes

1. Preparation
Documentation: None

7. Have 4 copies of the ethics form (Be sure to number the forms with the participant numbers & name)
8. Have 4 copies of the questionnaire & pens (Be sure to number the forms with the participant numbers ONLY)
9. Ready the vests and markers
10. Ready the wireless microphones
11. Ready both cameras with tapes inserted. LABEL the tapes properly!
12. Ready the mini-disc reorder with disc inserted. LABEL the disc properly!
13. Ready snacks and water (chips, bottled water, cookies)
14. Turn on the projectors

2. Meet participants: (5 minutes)
Documentation: None

7. Introduce everyone involved in the evaluation
8. Provide an overview of the evaluation session. STATE THAT THEY CAN STOP AT ANYTIME.
9. Provide ethics consent form for signature (Be sure to witness the forms – anyone of us can do that).

3. Introduction and warm-up session (15 minutes)
Documentation: Occasional Handheld camera for presentation purposes
The warm-up should be without the system. A series of simple and quick puzzles are given to the group who try to "solve" it through coordinated body movements (the goal is to connect puzzle solutions with body-movements and to see how the group solves the puzzle, i.e. by talking).

The facilitator introduces the concept of the game by comparing it to the game of "hot and cold." The facilitator leads the group through each of the puzzles by providing the word puzzle and telling the group whether they are close or not by using the words "cold", "cool", "warm", "hot" and by letting them know when they have completed the puzzle (In the process the facilitator may have to explain that gestures or absolute locations are not significant):

Puzzle 1: "high-low" Solution: look for movement that has the whole group low.

Puzzle 2: “sticks in the mud” Solution: look for the half the group to be standing up straight and still and the other half lying down still. Suggest that the group try to hold the solution for 3 or more seconds so we can be sure that they did not “accidentally” solve it.

Puzzle 3: “All Found around thinly – Fall into a swarm” Solution: a two part in sequence, first all spread out and then clustered together on the ground. Explain that the solution is a two part sequence.

4. Introduction to the system (10 minutes)

Documentation: Occasional Handheld camera for presentation purposes

1. Provide an overview of the game, describing the levels, puzzles, goals at each level, role of the system (mention the circle, and that this is a research prototype that has occasional glitches and can crash; that they need to be attentive to the system and that it has a slight delay in its response)
2. Play audio rewards to the players
3. Prepare each player with the vests and wireless microphones (ATTENTION: Make sure that the numbers on the microphones and vests match the number the participant number (for example, participant ‘C1” is “player 1” and should use the microphone and vest labeled “1”); Make sure that the microphone is securely attached to the back or in the pocket of the players; and the microphones are on).

5. Playing the game (levels 1-4) (maximum 65 minutes)

Documentation: START to record with the two video cameras and mini-disc recorder; occasional Handheld camera for presentation purposes

4. Perform an audio test to be sure all the audio is being captured and be sure to record it. Ask player 1 to say player 1 so we can later recognize the voice. You will need to adjust the audio levels based on the level meter in the camera. Repeat this process for each player.
5. Players play levels 1-4 until all levels are completed or the maximum time is reached. Explain to them that they have a maximum of 60 minutes to play. If they do not complete the levels, explain the solution to the last level they are on.

6. Break (5 minutes)

Documentation: None PAUSE THE CAMERAS & MINISDISC!

Offer participants, juice, water and chips.

7. Playing the game (levels 5-6) (15 minutes)

Documentation: START to record with the two video cameras and mini-disc recorder; occasional Handheld camera for presentation purposes

Players play levels 5-6 until all levels are completed or the maximum time (15 minutes) is reached.

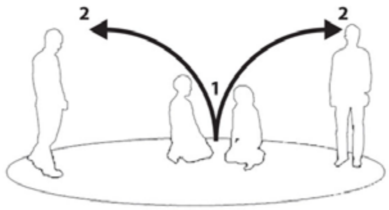
8. Questionnaire (15 minutes)

Documentation: None

Questionnaires are distributed and players complete the questionnaires. Players are thanked and certificates are given. Ask participants to tell others about participating in the evaluation.

Socio-ec(h)o Manual

Level Four



Puzzle:
"Big bang!"

Solution:
• This solution has two parts.
• Part one: all players need to be low to the ground, either sitting or crouching close together in the middle of the circle.
• After hearing an audio reward, continue holding this position for at least three seconds until an audio reward is heard. This completes part one.
• Part two: all players need to stand up and move to the outer edge of the circle and stand still. Players need to be equal distance apart from each other.
• Continue holding this position for at least three seconds until a final audio reward is heard and the video changes to show the solution.

Tips:
• Be sure all players are low enough and close enough together in part one.
• Be sure all players hold the solution in part one long enough before solving part two of the puzzle.
• Be sure you are not moving out of the circle or too close to the edge in part two.

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Level One

Puzzle:
"Lo and Behold"

Solution:
• All players should be low to the ground, either sitting or crouching.
• After hearing an audio reward, hold the position for at least three seconds until a final audio reward is heard and the video changes to show the solution.

Tips:
• Be sure you are low enough.
• Be sure that all players are holding the position together.

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Level Two

Puzzle:
"Sloe and low like a plum turtle"

Solution:
• All players need to be low to the ground on their hands and knees.
• While in this position, move slowly within the circle.
• After hearing the first audio reward, continue moving in this position for at least three seconds until a final audio reward is heard and the video changes to show the solution.

Tips:
• Be sure you are low enough.
• Be sure you are moving slow enough.
• Be sure that all players are holding the position and all players are moving at a similar speed.

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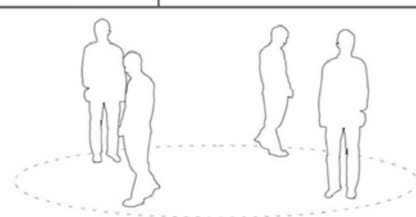
Level Three



Puzzle:
"All rolling in a bowl"

Solution:
• All players need to be upright and quickly moving around the inside edge of the circle.
• Players need to maintain some distance between each other as they move.
• After hearing the first audio reward, continue the solution for at least three seconds until a final audio reward is heard and the video changes to show the solution.

Tips:
• Be sure you are moving fast enough.
• Be sure that all players are sufficiently apart.
• Be sure you are not moving out of the circle or too close to the edge.

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Socio-ec(h)o Study Post-Questionnaire

Participant # ____

In the questions below, we ask you to rate an answer along a scale of 1-5 or circle "No opinion," if you cannot rate an answer. Some questions we ask you to provide written answers. If the space provided is not sufficient please use the back of the sheet.

Please ask if you have any questions about completing this questionnaire.

Section 1

1.1. How confident do you feel about using the system after this evaluation (circle one)?

(not very)	no opinion	1	2	3	4	5	(very)

1.2. Did the system require a large effort to learn (circle one)?

(very large)	no opinion	1	2	3	4	5	(very little)

1.3. Was the system more or less helpful in solving the puzzles as the evaluation progressed (circle one)?

(less)	no opinion	1	2	3	4	5	(more)

1.4. Did your attitude toward the system become more or less positive as the evaluation progressed (circle one)?

(less)	no opinion	1	2	3	4	5	(more)

1.4a Please describe in what respect you feel positively or negatively toward the system?

Section 2

2.1 How well did the system respond to all your actions from the start of solving the puzzle to solving it (circle one)?

(not well)	no opinion	1	2	3	4	5	(very well)

2.2 How well did the system provide useful cues in helping you evaluate how close you were to solving a puzzle (circle one)?

(not well)	no opinion	1	2	3	4	5	(very well)

2.2a Can you describe how the system provided or did not provide useful cues in evaluating how close to were to solving a puzzle?

2.3 How well did the system respond when you were having problems solving a puzzle (circle one)?

(not well)	no opinion	1	2	3	4	5	(very well)

2.3a Can you describe how the system responded when you were having problems solving a puzzle?

2.4 How well did the system support coordinating information and actions within the team (circle one)?

(not well)	no opinion	1	2	3	4	5	(very well)

2.4a Can you describe how your team coordinated information and actions?

2.4b Can you describe how your team was organized and supported leadership?

Section 3

3.1 Do the lights and audio work together to help you in the game (circle one)?

(not well)	no opinion	1	2	3	4	5	(very well)

3.1a Can you describe how the lights and audio worked together to help you in the game?

3.2 How effective was the audio feedback in helping you solve the puzzles (circle one)?

(not effective)	no opinion	1	2	3	4	5	(very effective)

3.3 The audio response in which levels was most effective in helping you evaluate how close you were to solving a puzzle (circle one or more)?

Levels (in order)	no opinion	L1	L2	L3	L4	L5	L6

3.4 Which sounds worked better in the game (circle one or more)?

Sound category	L1(Music)	L2(Music)	L3(Rocks)	L4(Fire)
	L5(Water)	L6 (Forest)		

3.5 How well does the virtual system (lights, audio, video) integrate with the physical and architectural space (circle one)?

(not well)	no opinion	1	2	3	4	5	(very well)

3.6 Is the environment created by the system conducive for a game (circle one)?

(not well)	no opinion	1	2	3	4	5	(very well)

3.6a Can you describe how the environment created by the system was conducive or not conducive for a game?

Section 4

4.1 Were parts of the system not helpful or ignored?

4.2 Did the system not respond to some important actions in solving the puzzle?

4.3 How did the system respond when you were unsure or confused?

Section 5

5.1 Any additional comments?

Please note: If you are an **IAT332** student, please remember to write the 1-2 page reflection (as part of your assignment) right after the session when your memory is still fresh.

Thank you for completing this questionnaire and participating in this research!

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