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A case study of intended versus actual experience of adaptivity in a tangible storytelling system

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Abstract This article presents a case study of an adaptive, tangible storytelling system called "The Reading Glove". The 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. The Reading Glove is an interactive storytelling system featuring a wearable, glove-based interface and a set of narratively rich objects. A tabletop display provides adaptive recommendations which highlight objects to select next, functioning as an expert storytelling system. The recommendation engine can be run in three different configurations to examine the effects of different adaptive methods. The study of the design process as well as the user experience of the Reading Glove allows us to develop a deeper understanding of the experience of adaptivity that is useful for designers of intelligent systems, particularly those with ubiquitous and tangible forms of interaction.

Keywords Adaptivity · Tangible computing · User models · Recommendation systems · Expert systems · User experience

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1 Introduction

The goal of this research 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 much more 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 education, 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.

This article presents a case study of The Reading Glove, a wearable and tangible interactive storytelling system with an adaptive component that acts as an "expert storyteller" that leads the reader through the narrative. The Reading Glove is an interactive narrative installation comprised of a large tabletop display surface, a wearable RFID enabled glove, and a collection of narratively rich objects. When readers pick-up objects from the surface, an associated fragment of audio narration is triggered. At the same time, a reasoning engine is tracking the reader's choices and displaying navigational recommendations on the display beneath the objects to assist the reader in solving the puzzle of the narrative. The Reading Glove uses the metaphor of psychometry to inspire a "hands on" interaction with narrative objects. Interactors using the Reading Glove explore and reveal the "memories" of physical artifacts by handling them, uncovering pieces of a non-linear narrative distributed across the objects.

In this paper, the complete design process of the Reading Glove is analyzed, starting with the initial inspiration, moving through the multiple iterations of the system and concluding with a 30 participant user study of the final version. This detailed study of a single system investigates three research questions related to the experience of adaptive systems with tangible and ubiquitous components: (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? We start addressing these questions by first discussing our case study methodology in Sect. 2, then considering the relevant literature in Sect. 3. In Sect. 4 we provide an overview of the design of the Reading Glove system. Section 5 looks at the participant experience of using the system, and in Sect. 6, we compare our designerly intentions to the actual participant experience. In Sect. 7, we summarize our findings and make recommendations for the design of tangible computing system with adaptive components.

2 Methodology

This research takes the form of a descriptive case study (Baxter and Jack 2008). A case study is an in-depth study of a specific, bounded phenomenon through multiple sources of data (Creswell 2003). Case studies look at a social phenomenon, focusing on detailed descriptions, interpretations and explanations that participants attach to the phenomenon (Swanborn 2010). 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 primary limitation of a descriptive case study is that is confined to describing a phenomenon in detail; it does not provide evidence to explain or prove the cause of that phenomenon. Because it is a detailed study of a single case, it does not always prove easy to extrapolate beyond the boundaries of that case and make generalizable claims. The phenomenon under study here is the design of a tangible computing system with adaptive components. Adaptivity, and most particularly the user experience of adaptivity, is an under theorized and under examined facet of computing systems. The design case that we examine here is a 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 challenging to disentangle, thus making it an ideal situation for the holistic approach of the case study methodology (Swanborn 2010).

2.1 Research questions

To investigate the phenomenon of an adaptive system, we 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?

2.2 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 terms 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 our own personal experience as designers and researchers. In Sect. 6, we present evidence from the analysis that addresses these claims.

2.3 Units of analysis

The studied case is a specific design project, the Reading Glove, with two embedded units of analysis, the system designers and the participants who experienced the system (Yin 2009). The first unit of analysis in studying this system data collected about the designers and their intentions while designing the system. The system was designed over the course of 2 years, from 2009 to 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 and 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.

2.4 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, we developed an initial conceptual framework (Fig. 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, who 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

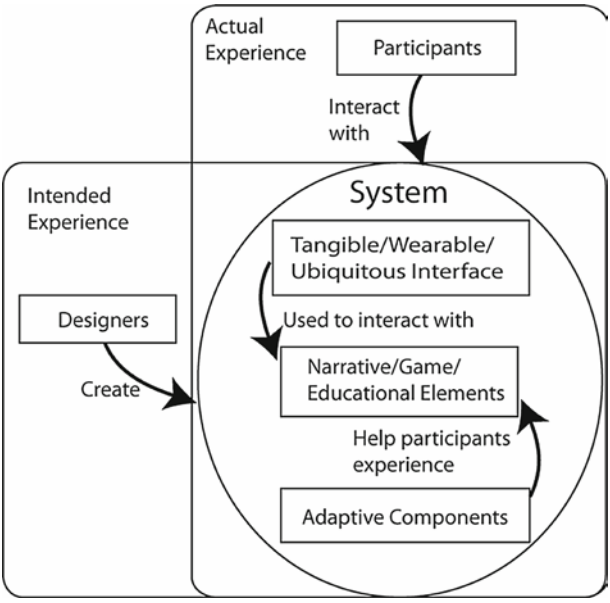

Fig. 1 Starting conceptual framework

framework is articulated, changed, and made specific to the case over the course of the analysis; in particular, the relationship between the designers' intentions and the participants' actual experience is explored.

2.5 Study protocol

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.

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 Sect. 4.2.3 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 interact 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.

2.6 Data collected

We 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. We collected pre and post interaction questionnaires involving mostly Likert-scale questions on different topics. The pre-interaction survey asked basic demographic questions and probed for certain key characteristics, such as experience with similar systems, general patterns of technology use, and so forth. The post-interaction survey 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. Video recordings of participants interacting with the system were collected. 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. System logs provide valuable details about specific features of the experience. The Reading Glove system logs allowed us to extract information about how long the interaction lasted, whether they followed the recommender system, in what order and how many times they picked up objects, and whether or not they interrupted the audio playback before it was finished. Semi-structured interviews were conducted with participants following their interaction with the system. These interviews were recorded and the dialogue transcribed for analysis. The interview data was analyzed primarily for information about the experience participants had of the system: what kind of sense they made out of it and how they arrived at that understanding. Design documentation, including wireframes, interactions models, design scenarios and technical reports, were collected. Published papers on the project also provide insight into the development and motivations of the design process (Tanenbaum et al. 2010a,b, 2011a,b).

2.7 Analytic strategies

This is a mixed method study with a predominately qualitative focus. To answer the first two research questions and propositions, our 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. These transcripts were coded and then categorized into themes to allow for a deep understanding of the experience from the participant's point of view (Miles and Huberman 1994; Corbin and Strauss 2008). The results from this analysis are supported by data from the surveys, system logs, and video recordings of the participants interacting with the system. Some of these supporting results are quantitative in nature, including descriptive and correlational statistics. To answer the third research question and associated proposition, we combine the participant-focused analysis described above with the description of the design of the Reading Glove system laid out in Sect. 4. This system description focuses on developing an understanding of the goal of the system, the designers' intended participant experience, and the theoretical commitments underlying it. These intentions are compared to the actual experience of the system.

3 Literature review

3.1 Adaptivity and user modeling

User models are increasingly frequently deployed in ubiquitous and mobile computer environments. One of the most prevalent uses of user modeling outside of the desktop is in mobile guide systems, often termed "information delivery systems". They are commonly seen in museum and art gallery spaces and used to access additional information about the objects on display based on personalized interests and preferences (Hatala and Wakkary 2005; Kuflik and Rocchi 2007; Zimmerman and Lorenz 2008). Another growing area for user modeling is in "smart home" environments which support domestic living in a variety of ways, ranging from maintaining entertainment preferences through providing health care and assisted living functionalities (Vildjiounaite et al. 2007). In a more playful arena, user models have also been deployed in experiential and aesthetic applications such as installation art, games and interactive narrative in ubiquitous spaces (Natkin and Yan 2006; Thue et al. 2007a). At the moment, most ubiquitous systems provide their adaptive effects via digital displays and other media platforms, but there is a great deal of potential for more widespread use of tangible, physical effects as well, such as adjusting the temperature, turning on and off lights, or even integrating servomotors that could open or close doors in a home.

As computation is embedded in the environment and in normally non-computational devices, however, 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 don't 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).

One way to understand this challenge is through the lens of mental models, a fundamental concept in human–computer interaction. Mental models are the internal representations that people construct of themselves, their environment, the people around them, and the things they interact with (Norman 1988). When dealing with designed interactive systems, two mental models come into contact with each other. One is the designer's mental model, as instantiated in the system. The other is the user's mental model, which is developed through interacting with the system. The models are almost assuredly not always in perfect agreement, and bringing them into alignment is a significant design challenge. When the mental models of the designer and user are widely diverged, users can easily become frustrated as the system will act in seemingly incomprehensible or unexpected ways (Norman 1988). Alignment of models is not the only concern in interaction design, of course, as it does not provide much traction on important issues such as aesthetics, emotional impact, meaning, or values. But when dealing with novel interaction paradigms such as tangible computing, the issues around model alignment often come to the forefront as people attempt to make sense of the new system and how to use it. Adaptive systems can be a powerful tool when provided with the ability to recognize and accommodate possible misalignments between the conceptual models of the designer and the user. We use the Reading Glove system to examine what happens when designer and user mental models are not in alignment and to provide some suggestions on the role adaptivity can play in bringing them into alignment.

3.2 Tangible computing

Despite its relative youth, the field of tangible computing has given rise to a large number of frameworks, models and other systems that try to capture what is unique about tangible computing and what the key concerns are for design in the field. A full review of all the current theorizing is outside the scope of this paper, but a recent conference paper reviews many of the major ones and comments on their diversity and

overall lack of consensus (Hermann and Weber 2009). One of the canonical properties of tangibles is a meaningful coupling of physical and digital representations (Ullmer and Ishii 2001). Their approach is primarily systems-oriented, focusing on how tangible systems allow the integration of system control and information representation in physically interactive objects. Since this foundational discussion of tangible computing, a number of alternative frameworks for understanding tangibility have been proposed. Hornecker and Buur (2006) put forth a framework for tangible interaction, which they define quite broadly so as to encompass tangible and ubiquitous computing, interactive environments and even mixed/augmented reality. They describe previous tangible interface work as falling into three camps: a "data-centered view", an "expressive-movement-centered view" and a "space-centered view". Their framework consists of four interrelated themes which move from specific to more general: tangible manipulation, spatial interaction, embodied facilitation, and expressive representation. Similarly, Klemmer et al.'s 2006 paper on *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: thinking through doing, performance, visibility, risk, and thickness of practice (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, playing catch, or even just walking are characterized by a variety, richness, and complexity of physical actions. While there are a large number of frameworks for characterizing tangible and embodied interaction, Hornecker and Buur's framework and Klemmer et al.'s stand out in that they focus less on technology or system characteristics and more on the experiential characteristic of tangible interaction, and on the ways in which embodied interaction is just a further exploration of common ways of interacting with the world. In designing the Reading Glove, we aimed to explore how using the commonplace action of grasping, holding, and playing with objects would influence the experience of the story and the adaptive feedback.

3.3 Interactive storytelling

The Reading Glove uses physical objects and a tangible interface to tell an interactive story. There have been several previous attempts to merge research in interactive narrative with research in tangible interaction. One popular approach has been to distribute narrative fragments across a series of tangible objects. Holmquist et al. (2000) describe an object-based tangible storytelling system in which readers used a barcode scanner to retrieve video clips in a narrative puzzle. Mazalek et al. (2001) created a tangible narrative system called genieBottles in which readers open glass bottles to "release" trapped storytellers (genies) which reveal fragments of narrative information. Mazalek et al. (2002) also designed graspable "pawns" for the Tangible Viewpoints project, which were used to access different character perspectives in a multi-viewpoint story. Unfortunately, all three of these systems provide little to no data on how users of the system experienced the tangible interface or the story being presented. Most of the discussion of these systems is oriented towards the technical

challenges of the interface and sensor design. While a number of interactive systems have used a combination of glove-based interfaces and RFID technology, none of them have dealt specifically with storytelling. Instead, research with glove-based interfaces tends to focus on gaming applications (Konkel et al. 2004; Martins et al. 2008) or assistive and enabling technology (Lustig et al. 2007). The exploration of how users experience a story told via an adaptive, tangible and wearable interface has not been undertaken in any detail.

Most work on intelligent narrative systems centers around how to adapt the story and environment to choices made by the interactor, i.e., how to restructure the plot so that story coherence is maintained or how to create non-player characters that can interact with the player in a life-like manner. A common approach to this is a form of case-based-reasoning used to create "Drama Managers": AI agents that act like "directors" to parse the various goals of subsidiary AI "actors" against a set of higher-order narrative operators, for example (Swartout et al. 2001; Szilas 2003, 2005; Riedl 2005; Roberts et al. 2009). The most well-known and successful of these "interactive dramas" is arguably Mateas and Stern's *Façade:* a simulated dinner party in which the interactor negotiates her relationship (via typed natural language) with two AI agents whose marriage is in crisis (Mateas and Stern 2005). As with most current interactive storytelling systems, the player is cast as a first-person participant in the narrative, and allowed to freely explore the simulated world, within the designed interactional constraints of the system. The adaptive components of systems like *Façade* evaluate the actions of the player and attempt to reconcile them with the high-level narrative goals of the director agent, and the local goals of the virtual characters, to create a story that has plot coherence, narrative arc, emotional verisimilitude, and internal consistency.

The other common use of adaptive systems in interactive storytelling is to employ a form of player preference modeling to attempt to infer stylistic or affective preferences, which can then be used to alter how the narrative is presented to the reader. These include user modeling systems that cast players into different stereotypes in order to adapt character options and dialogue (Thue et al. 2007a,b), and systems that create user models of different affective preferences to adapt lighting, audio, and camera angles (Seif El-Nasr 2004; Tanenbaum and Tomizu 2007). Hybrid systems, such as the one described in Sharma et al. draw on a model of player preferences to help specify higher-order narrative goals for drama management systems (Sharma et al. 2007).

In contrast to these systems, the narrative and the environment in the Reading Glove system are fixed. The interactor selects what order the story is heard in, but cannot fundamentally change what happens. The reasoning engine that drives the guidance system on the tabletop (described below) thus functions essentially as a knowledge-based recommender, helping the "reader" move through the story in a coherent manner. As a result, the intelligence techniques used in the system are most similar to those used in recommender systems in educational and informational applications, where the goal is to present a static body of content to the user in an intelligent and dynamic manner based on her choices and actions (Hatala and Wakkary 2005; Damiano et al. 2008; Hatala et al. 2009).

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

4 The Reading Glove system

The Reading Glove project is a multi-year research endeavor undertaken by PhD candidates Karen and Joshua Tanenbaum with the support and input of professors 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, 2011b), 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 Fig. 2). These additions assist interactors in navigating the narrative while also allowing the study of user perceptions of adaptivity.

4.1 Interaction and story

Interaction with the Reading Glove system starts with the "reader" putting on a soft fabric glove and picking up one of the objects sitting on a tabletop. This tabletop displays pictures of each object arranged in a rectangle. 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 twentieth 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.

4.1.1 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 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.

4.2.1 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 Fig. 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

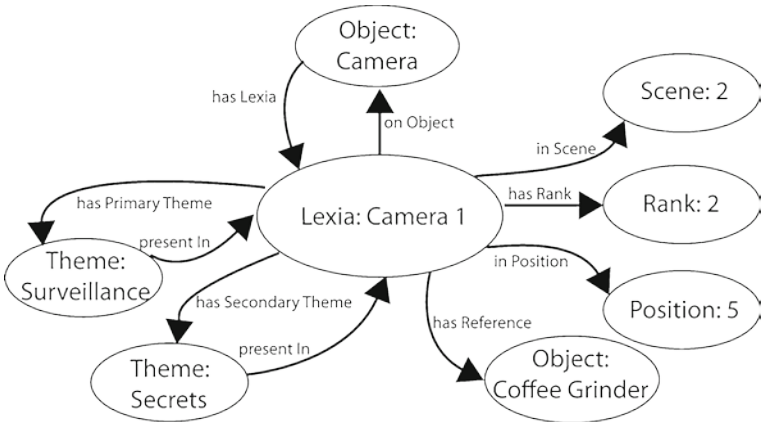

Fig. 3 The structure of the ontology for one lexia

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.

4.2.2 Reading Glove recommendations

The Jess rules use this knowledge base 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 Fig. 4). The display remains in this state until another object is picked up, at which point in reverts to the neutral state.

4.2.3 Reading Glove recommender types

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

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

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

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 1 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.

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. So if the seed lexia is in position 5, the candidates in positions 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

Table 1 Weightings for matching themes

	Candidate	
Seed	Primary theme	Secondary theme
Primary theme	50	20
Secondary theme	30	40

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.

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.

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.

5 Experiencing the Reading Glove

5.1 Proposition 1: Intended benefit versus actual experience

The first proposition that we are 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, we examine data related to each of the two units of analysis: designers and participants. We begin with the designers. We identified the intended benefit of the adaptive components from the following data: our personal experience of the design process; collected design documentation; and published work. We also

looked at the user study data to see what the actual experience of the system was like for the participants.

5.1.1 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. 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, 2011b). Here we 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, we 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.

We conducted a pilot user study with this version of the glove, with seven participants exploring the objects and the story for between 10 and 15 min. The clearest outcome from this pilot study was that the random access to the pieces with the multiple lexia was problematic. None of the seven 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 that was used in the larger user study, 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 three 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.

5.1.2 Participants: actual experience

With a better understanding of the design process and the decisions that went into creating the system in place, we now turn to an analysis of the actual experience of the participants in the 30 person study described in Sect. 2.5 above. The first element we looked at was the overall experience participants had, to establish a baseline. If the participants did not find the system basically enjoyable and functional, it would be difficult to use 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 eight questions. The questions were paired as negative and positive versions of four basic concepts—Ease of use, Enjoyment, Desire to Experience the System Again, and Perception of Agency—with participants asked to rate them on a 5-point scale consisting of "Strongly Disagree", "Disagree", "Undecided", "Agree", "Strongly Agree" and "No Answer". 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 we 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, we recovered numerical information on a variety of characteristics of the experience (see Table 2). The first metric we 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

Table 2 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

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 we looked at how long the participant spent with the system. The total running time of the story, listening to each lexia once, is 8 min and 50 s. On average, participants spent 17 min 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 min and 30 s interaction with the system, with a range from 7 min and 3 s to 12 min and 58 s. With this version, the shortest interaction time was 9 min, while the longest was 46. This suggests that the adaptive display drove a deeper and longer engagement with the story.

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. The mean numbers for each metric suggest that the average experience was to listen to the story one and a half times before stopping.

Describing the experience After getting a handle on some of the quantitative aspects of the participants' experience, we 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.

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, we 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 described being frustrated by this discovery, and by the inability to simply activate the objects in a linear order. Other participants experienced a 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…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.

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 describes this phase in terms of the different locales within the narrative, and explains how she used objects associated with those locales to try and get to moments where she wanted more information. 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 final explorations as "spastic", intended to break his previous interaction patterns. His "reward" for these explorations was the discovery of a piece of overlooked information from the very beginning of the story. 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.

Experiencing adaptivity In this section, we 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, who said:

> It looked like there were clues as to where to go next. By and large I ignored them…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, we 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…. [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.

Differences across conditions So far, we 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

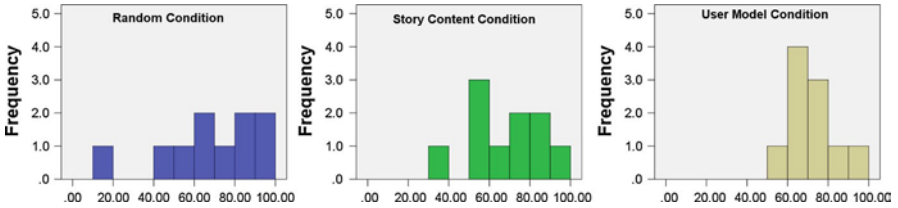

Fig. 5 Percentage of times recommendations were followed, by condition

particularly rewarding." These experiences convinced them to return to following the recommender's advice.

Above we discussed the amount of time the recommender was followed, and Fig. 5 breaks this statistic down further by condition.

An ANOVA found no statistical significance 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.

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.

We 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. We 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. We 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 Fig. 6). 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.

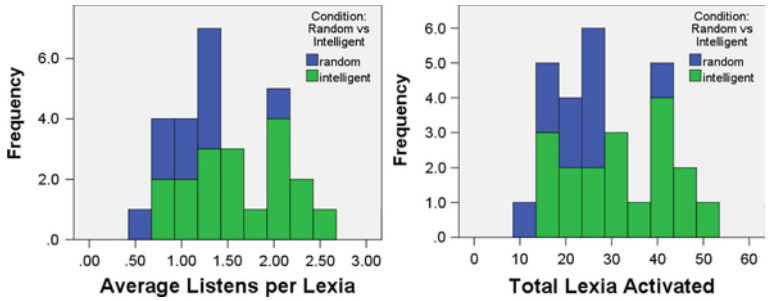

Fig. 6 Frequency distributions for two behavioural measures separated by condition (random = *blue*, intelligent = *green*). (Color figure online)

We 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 we 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.

5.1.3 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.

5.2 Proposition 2: Interaction with tangibility and 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, we look at how the tangible glove and objects interacted with the adaptive components of the system. First we 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 we turn to the interview and observational data from the user study to understand how the participants experienced the tangible and adaptive elements.

5.2.1 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 second inspiration was the notion of *boundary objects*, a sociological term for artifacts that exist between two different worldviews. Boundary objects are sites of negotiation between opposing perspectives, and allow members of different groups to translate between a familiar view and an alien one (Star and Griesemer 1989). The idea of boundary objects was used to facilitate "readers" of the system in entering the storyworld, as well as an entry point for understanding the wearable glove-based interaction. 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, a glove was constructed which gives 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.

5.2.2 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, we 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 above; 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…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…. It's interactive, in a very analog way…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.

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.

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 manoeuvre 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, but 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.

5.2.3 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.
- They intended the objects to act as "boundary objects" to draw people into the world of the fiction.

Participants

- Some participants experienced deep engagement with the objects, to the point of distraction.
- Others wanted more functional interactions with the objects, with the physical interaction leading to an expectation of some kind of system-based response.
- Some participants had little interest in engaging physically with the objects.

5.3 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, we draw on the analysis already completed in the sections above, and add in some additional questionnaire and interview data.

5.3.1 Designers: goals of the adaptivity

In Sect. 5.1.1 above we discussed the intended benefit of the adaptive components, which was to assist the reader in navigating the non-linear story.

5.3.2 Participants: actual adaptive effect

With proposition 1, we 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 we explore in more detail where the participants thought they might be seeing adaptive effects, if not in the intended aspect of the experience.

Ascription of adaptivity In addition to the ease of use and enjoyment of use questions described above, we also asked in the post-interaction survey whether or not participants felt like their actions 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 Fig. 7).

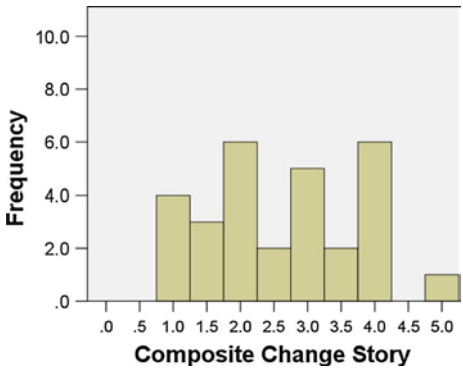

Fig. 7 Survey response on whether or not interactors felt they changed the story

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.

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 two 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 in your 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.

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 "And 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."

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.

5.3.3 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.

6 Relationship between design and experience

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

6.1 Proposition 1

In examining proposition one, we were 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 we 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

we 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 figuring out the system as well as the story 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 experience. Finally, we 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.

6.2 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 Fig. 8, and represents a specification of the initial conceptual framework laid out in Sect. 2.4 above.

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 (Fig. 9). We 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

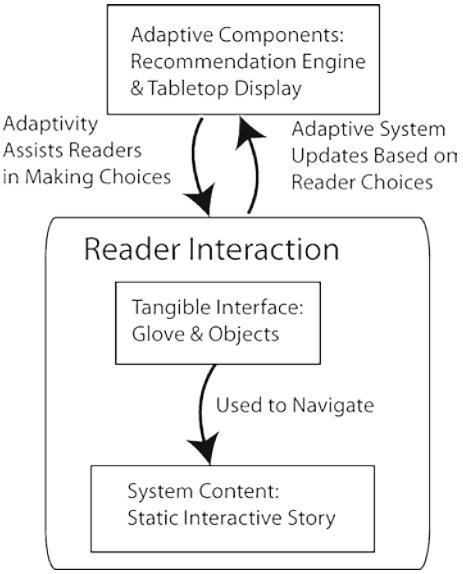

Fig. 8 Designers' understanding of the Reading Glove

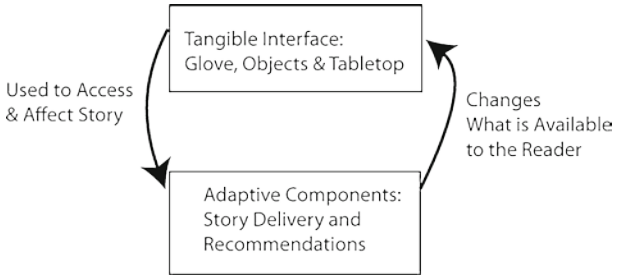

Fig. 9 Participants' understanding of the Reading Glove

conveying useful information to the participants. Clearly elements of the design are activating a set of expectations in the participants that the system cannot always deliver on.

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

6.3 Proposition 3

Propositions 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

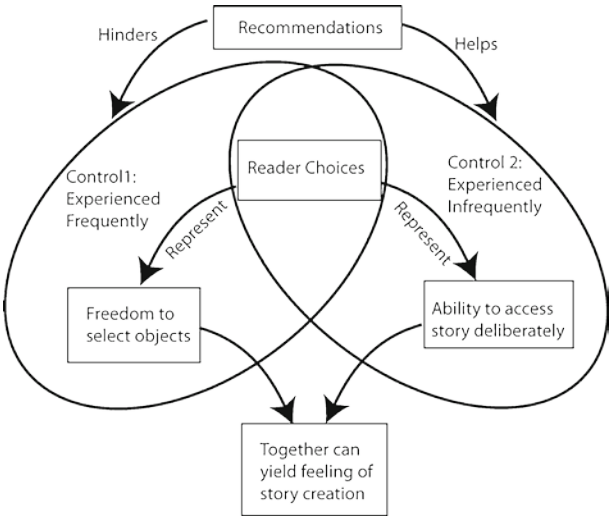

Fig. 10 Participant's experience of choice, control and creation

"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. We 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. In Fig. 10, we illustrate the dynamics of these two types of control.

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 memorable 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.

6.4 Design guidelines

Using the concepts arising from the proposition-based analysis, we set forth design considerations in the form of questions. 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.

6.4.1 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?

6.4.2 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?

6.4.3 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?

7 Conclusions

Through this case study, we have examined the differences between the intended and actual experience of an adaptive system and set forth a series of concepts and related design guidelines drawn from our analysis. We have highlighted the complexity involved in designing adaptive components for computing systems that make use of tangible and other novel interface styles, examining some of the experiential effects of these new interaction paradigms. In the analysis of the user study data, the interconnected notions of control and choice came to the forefront, and we have attempted to unpack the complex relationships between these two concepts and the experience of using the system. We have highlighted areas for future work in adaptivity, related to helping people make sense of novel interactions and grapple with new paradigms. We attempted to develop a detailed understanding of the stages people move through in grappling with new technology and suggest that adaptivity could be put to good use in detecting and responding to the stages that individuals are in. With regard to tangible computing, we suggest a need for more detailed study of the experience of using these systems, to learn how people construct and modify their mental models of the interaction process. We noticed that participants easily transferred the affordances of the tangible system to their assumptions about how the more abstract narrative domain would work, such as thinking they could organize the objects in linear story order. 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 we hope this paper is a good first step to unraveling from of the complexity inherent in this task.

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