Designing a Museum Multi-touch Table for Children

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Abstract. Tangible user interfaces allow children to take advantage of their experience in the real world with multimodal human interactions when interacting with digital information. In this paper we describe a model for tangible user interfaces that focuses mainly on the user experience during interaction. This model is related to other models and used to design a multi-touch tabletop application for a museum. We report about our first experiences with this museum application.

Keywords: tangible user interfaces, multi-touch table, tabletop, information access, children.

1 Introduction

A few decades ago, Human-Computer Interaction was largely restricted to traditional graphical user interfaces on computers with rectangular screens and mouse and keyboard as input devices. In that time [1] proposed to make computing truly ubiquitous and invisible and they introduced tangible user interfaces as a way to make digital information tangible. In these interfaces physical controls of digital information play a key role. This allows people to take advantage of their experience in the real world with multimodal human interactions.

The theory of embodied cognition shows the salience of tangible interaction for children. It is the merging of cognition and action which allows to easily manipulate the world and offload cognition while doing so [2]. Hence, for children, who in general have less abstract reasoning skills, tangible interfaces are in particular useful. The smaller the gap between real-world manipulation and digital manipulation, the easier the access to the digital information becomes, especially for young children.

Tabletop environments have been shown to allow natural interaction using tangible interaction elements [3]. All kinds of physical objects in the environment can be equipped with unobtrusive sensors in such a way that the children interact with their tangible surroundings. For instance in the Navigational Blocks project [4], the use of physical objects to represent data queries allowed people to explore relationships between topics and retrieve information. The tangible objects help users, especially children, to learn through touch and direct manipulation of objects [4].

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Within the European project PuppyIR access to information for children is central. Unfortunately the current tools for information access offered on the Internet are not adequate for children. Interfaces are typically created for adults, information retrieval methods are based on the perception of relevance by adults, and services are typically constructed based on the idea of the information needs of adults. Part of easing the access is through the use of intuitive interfaces. A tangible tabletop is, as explained, suitable to this aim.

The context for this paper is an educational museum that aims at a broad audience. Its main theme is the human and his relation with nature, culture, society, science and technology. This is the theme of the permanent exhibition of the museum as well. The museum functions as a test environment to alter the access to the information contained in the permanent exhibition.

This paper explores the possibility to enhance the access to information using tangible interfaces. Models for tangible interfaces are discussed in Section 2. A tabletop interface will be used to direct the visitors through the museum, adapted to the interests of the user. The development of this multi-touch tabletop interface is described in Section 3. Finally, Section 4 discusses preliminary experiences with the interface within the museum context.

2 A Children Specific Design Model for Tangible Interfaces

In the model we propose for PuppyIR, the design concepts and heuristics are grouped in four themes: (1) Physical and digital representations; (2) Actions and effects; (3) Exploration and collaboration; and (4) Engagement and fun. These themes are built upon other, related, models for tangible interaction. See Table 1 for an overview of the model and its related models. The model is tailored for the design of tangible interfaces for children.

2.1 Physical and Digital Representations

The theme *Physical and digital representations* refers to the appearance of the physical objects and the relation with the digital representation of the objects. Are representations naturally coupled? Are they meaningful and built on the user's experience? Do they invite them into interactions?

Part of this theme is related to what [5] refer to as expressive representation: the interrelation of physical and digital representations and to how users perceive them. Often hybrid representations combine physical and digital elements. [6] calls this semantic mappings: the mapping between the information carried in the physical objects and the digital aspects of the system. Young children (under seven) have difficulty relating physical manipulatives to other forms of representation. The ability to understand that one object can have multiple representations develops slowly.

To make an interface more suitable for young children, perceptual mappings can be exploited [6]. Various kinds of mappings between physical and digital space can be afforded by tangibles. The mapping between the perceptual properties of the physical and digital aspects of the system can rely on perceptual affordances or designed affordances. Designs that rely on perceptual affordances allow even very young children to explore these mappings. Designed affordances are opportunities for actions that are created through mindful design of artificial objects and environments. These affordances may be meaningful for adults, but for children age appropriate perceptual, cognitive and motor abilities and limitations need to be considered.

Table 1. Models of Tangible Interfaces

Theme	Related concepts of Hornbecker & Buur [5]	Related concepts of Sharlin et al. [7]	Related themes of Antle [6]
Physical and digital Representations: The appearances	Perceived coupling Representational signific. Tailored representation (Inhabited space – partly)		Perceptual mappings Semantic mappings
Actions and effects: How tightly are they related?	Isomorph effects Externalization Haptic direct manipulation (Inhabited space – partly) (Configurable materials)	Successful spatial mappings Unify input and output space	Space for action Behavioural mappings Semantic mappings
Exploration and Collaboration: How are they facilitated?	Lightweight interaction Embodied constraint Multiple access points Non-fragmented visibility	Enable trial-and-error activity	Space for friends Semantic mappings
Engagement and Fun: Are presence, motivation and user experience positively affected?			

2.2 Actions and Effects

The theme *Actions and effects* refers to the relation between the manual actions of users and their effects. This can be characterized by the following concepts [5]:

- Haptic direct manipulation: can users grab, feel and move the interaction objects?
- Externalization: can users use the objects as props to act with or think and talk with or through? Are tangible interactions salient to the overall use process?

- Isomorph effects: how easy is it to understand the relation between the manual actions of users and their effects? For instance because they are close in time, visibly nearby or of the same shape.

For children the relation between manual actions and their effects becomes more complicated. Children's developing repertoire of physical actions and spatial abilities for direct system input and control can only be applied successfully if the design is based on an understanding of how and why children's actions in space relate to changes in cognitive and motoric development.

An example of the benefits of a close coupling between action and effect comes from the repeatedly connecting and disconnecting of Lego blocks to better understand how different configurations relate to stability of the construction. Children use epistemic actions to facilitate the understanding of how things work. Hence, direct physical interaction with the world, by means of bodily engagement with physical objects, facilitates active learning and is a key component of cognitive development in childhood. External scaffolding (aids that include interactions with other children, adults, or aspects of the environment) is often used when executing epistemic actions [6].

The relation between action and effect can also be looked at from a behavioral perspective: the mapping between the input behaviors and output effect of the physical and digital aspects of the system. This is discussed by [7] with regards to their spatial mappings. [7] showed two conclusions: Physical/digital mappings must be successful spatial mappings, and physical/digital mappings must unify input and output space. A spatial mapping is successful if the spatial relationship between a physical object and its digital use is natural and intuitive and exploits spatial abilities known innately or learned early in life. And, when we play with a physical object the action space (our hands moving the object) and perception space (view and weight of the object) are perceived in the same time and place: tangible user interfaces designed to maximize input and output unification have a tight action-perception coupling leading to increased user identification between physical interface components and digital application objects.

2.3 Exploration and Collaboration

The theme *Exploration and collaboration* refers to the suitability of tangible user interfaces to facilitate exploration and collaboration. [7] clearly indicated the importance of exploration with the following design guideline: Physical/digital mappings must enable trial-and-error activity. Good physical tools enable people to perform goal-oriented activities as well as trial-and-error activities meant to explore the task space. They make sure that the cost of trial-and-error explorations is low. [5] further specify that tangible interfaces facilitate exploration and collaboration by:

- Lightweight interaction: a conversational style of interaction with rapid feedback, allowing users to proceed in small experimental steps.
- Embodied constraint: a physical set-up (such as size, form or location of objects) that leads users to cooperate by easing some activities and limiting others.

The importance of collaboration is clear from what [6] calls *space for friends.* This refers to tangible user interfaces which have both the space and affordances for multiple users. More explicitly, [5] define this as multiple access points: to distribute control such that all users can get their hands on objects of interest. This gives the opportunity to facilitate collaboration and imitation. Since collaboration and imitation are important ways for children to develop schemata level knowledge acquisition, it is important for designers of tangible user interfaces to understand the importance and mechanisms of imitation in experiential learning and to understand how to facilitate children's collaboration. Tangible systems have space and handles for co-located collaboration without the need to share input devices. Another topic belonging to this theme is imitation. Learning through imitation is very important for young children. When young children observe another person using unfamiliar objects they try to discern what the other person is using the artifact for. Tangible user interfaces are very suitable to foster imitative learning processes because of the physicality of tangibles combined with space for others and digital feedback.

2.4 Engagement and Fun

The *theme Engagement and fun* refers to the suitability of tangible user interfaces to increase presence, to be intrinsically and extrinsically motivating, and to create a positive user experience. Each of these aspects will be described.

Presence is the feeling of being in a mediated world; i.e., being fully engaged in a mediated activity. Accordingly, the degree of presence can be seen as the degree to which normal (psychological) processes are applied to a mediated world [8]. Tangible interfaces have the ability to increase presence because they allow to use normal (physical) processes to interact with a mediated world. Presence is closely related to the first two themes, where a decrease between action and effect and between physical and digital representations increases the use of normal psychological processes.

Motivation is an important user state, influencing the effort exerted and the persistence shown in solving a problem. It has been found to be a strong predictor of problem-solving success [9]. Motivation is often divided in intrinsic motivation; i.e., a genuine interest, and extrinsic motivation; i.e., some external incentive. An interface can be made extrinsically motivating by making it more game-like; i.e., with fantasy, challenge, rules and goals, sensory stimuli, mystery and active user control [10]. Intrinsic motivation can be explained by two determinants: a task performance that leads to a sense of mastery and competence, and a novelty that leads to a sense of curiosity, attention, and interest [11]. Moreover, it should be noted that feedback on and an overview of the progress with the activity are a key element of intrinsic motivation which should be supported by an interface [12]. An example of motivation based design is given by [5] as tailored representation: are the representations built on the user's experience and skills and do they invite them into interaction? A correct balance between the user's skills and the system's challenge (to use) leads to a motivating state.

The final perspective, user experience, takes a holistic view on engagement and fun. User experience is a rather fuzzy concept, often defined as technology use beyond its instrumental value. In other words, stating that it is the whole experience of an interactive system, contrary to only the instrumental, which creates value. Hence, the focus on user experience is broader than merely heightening the enjoyment of a system; the experience has many facets joining together. Several aspects of user experience have been identified; e.g., usability, beauty, affect, temporality, and situatedness. Together, these aspects explain part of the eventual user experience [13]. Hence, an interface should be usable (i.e., intuitive), support positive emotions, and be aesthetically appealing.

The presented themes will be useful to guide the design of a PuppyIR prototype and they will also be used to develop measures for user-centred evaluation.

3 Development of a Museum Application for Children

In this section we describe ongoing work on the design of a prototype touch-table application for a museum context. We explain design decisions by relating to the themes presented in the model in Section 2. The museum (Museon in The Hague, The Netherlands) is an educational museum with a permanent exhibition 'Your World, My World' about humans and their relation with nature, culture, society, science and technology. In the museum a multi-touch table is used at the beginning and at the end of the museum visit, by groups consisting of two to four children. Often one or two parents are also part of the group. The application at the multi-touch table is used to determine a route through this exhibition, based on the interests of the visitors. The goal is to give the children guidance and to optimize their museum-going experience.

The main screen that people see when they arrive at the table has the solar system as a background. When people touch this screen, particles appear with colored backgrounds. See Fig. 1 for a screenshot of this screen.

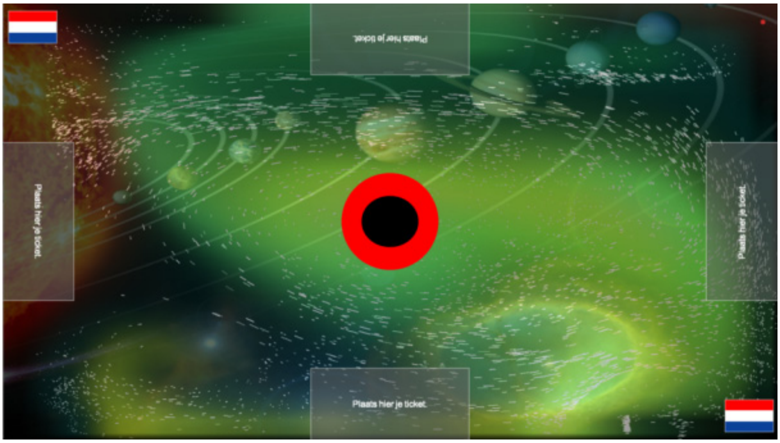

Fig. 1. The main screen of the touch table before interaction started

Interaction with this screen is not really part of the registration procedure but it is meant to be *engaging* and to *encourage exploration* by enabling trial and error activity and lightweight interaction. At the middle of each side of the table there are virtual boxes. These boxes can be used to register. *Collaboration* is facilitated by *multiple access points*, *non-fragmented visibility* and *space for friends*. Children who take part in the experiment get a ticket that fits in these boxes and that has a marker on one side that is recognized by the table and a barcode on the other side that will be used in the quest (see below). The initial game starts when people put the tickets in the boxes. Fig. 2 shows the situation that two people already registered successfully (the red circle becomes partly green then) and two people are still busy registering.

Fig. 2. Registration with the personal tickets

When all group members have registered, the participants get a screen (see Fig. 3) where they drag the characters of their name to a bar on the table, in front of them.

Fig. 3. Putting in the name of the children in the game

In the initial game people choose categories of subjects (i.e. parts of the exhibition) they are interested in. There are twelve categories represented by round images. Everybody chooses six of these categories. Here the theme *physical and digital representations* of our model is relevant. Are physical representations in the exhibition naturally coupled to the digital representations in the images? To answer this question more research is needed. Fig. 4 shows the screen where the people can drag the images they choose to the circles near their registration ticket. The theme *actions and effects* is also relevant here. By *direct manipulation* users choose images and move them to their own area. The relation between this manual action and its effect is easy to understand (*isomorph effects*) and the action-perception coupling is tight (*unification of input and output*).

Fig. 4. Choice of categories of subjects children are interested in

The chosen categories are used to determine a route through the exhibition room of the museum. In the exhibition room many (around 120) touch screens with barcode reader are available, close to the exhibits. The registrations tickets are used here to identify the children and to transfer information from and to the table applications. Based on the results of the initial game the participants receive a personalized quest of twelve questions to be answered at twelve different exhibits. After each good answer, the children choose a virtual object they like. People can help each other whenever they want. They are near to each other and interacting with the other group members. After all members of the group have finished the quest, they go to the multi-touch table again to do the end game.

Coming back to the multi-touch table the children use their tickets to login again. From the virtual objects collected during the quest the group chooses twelve different objects. In the end game these objects are in the middle of the table. Twelve boxes with words are positioned at the edge of the table (see Fig. 5). *Collaboration* is facilitated by visibility of the words from two sides. The task is to connect the words to the matching virtual objects by drawing lines. The children have limited time for this. After two minutes the connections are checked showing an animation: one by one the virtual objects are highlighted and the connecting lines become green when a connection is correct and red when it is not correct. The animation is meant to be *engaging* and *motivating*. After this animation the end score of the group is shown.

Fig. 5. Boxes with words that have to be connected with virtual objects in the end game

4 Observations and Conclusions

Interaction with the solar system on the main screen attracted many visitors and appeared to be *engaging*: children kept producing colors and stars for up to five minutes. While doing this they talked about fireworks, stars and imitating Harry Potter. Without much hesitation most children interacted with the table with both hands and together with other children. Only some very young children (younger than six years of age) started to interact very cautiously, with one finger. They cooperated while they tried to find out how the table worked. An often heard hypothesis was that the table reacted on heat. Some of the children discovered that the table already reacted when they hovered over it, which they found intriguing. We conclude that the solar system on the main screen *enabled trial and error activity* and *facilitated exploration and collaboration.*

The choice of characters and images appeared to be *intuitive*. Hence *actions and effects* were tightly related. In the end game children connect the words to the matching virtual objects by drawing lines. This appeared to be *less intuitive* than the other interactions on the table, especially for children under eight years old. Here the *actions and effects* relationship can be improved. However, with extra explanations and feedback, most children found out how it worked quickly.

During the animation that checked the connections drawn, nobody touched the table and the children were very attentive to see their results. This might indicate the animations were *engaging* and the children were *motivated* to have a high score.

In conclusion, these preliminary results indicate that for three out of four themes of the PuppyIR model derived in Section 2 the interactions at the multi-touch table seem to be well-designed: The interactions at the multi-touch table are *engaging and fun*, *facilitate exploration and collaboration* and most of the interactions are intuitive, hence *actions and effects are tightly related*. Only in the end game this relationship should be improved. Currently the interactions designed for the multi-touch table in the museum use no tangible, physical, objects (except for the registration tickets). Hence the first theme, *the appearance of the physical objects in relation to the digital representation*, seems to be irrelevant here. Tightly related, however, is the representation of parts of the exhibition of the museum in the round images children use to choose subjects they are interested in. If this coupling was clear is one of the questions we hope to be able to answer after we studied all the results of the experiments we did in the museum.

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