Tangibles: Five Properties to Consider for Children

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ABSTRACT

Tangible interaction offers school age children certain affordances for action based learning. In this paper I present and illustrate five properties of tangible systems which designers should consider. The properties are proposed based on analysis of relevant literature from cognitive psychology. This categorization provides the foundation for understanding how to design the physical and digital properties of tangibles to support the abilities and limitations of child users.

KEYWORDS

Tangibles, interaction design, children.

ACM CLASSIFICATION KEYWORDS

H.5.1 [Multimedia Information Systems]: Artificial, augmented and virtual realities, H.5.2. [Information Interfaces and Presentation]: User interfaces.

INTRODUCTION

The term tangible interaction as proposed by Hornecker and Buur [8] encompasses a broad range of interfaces and systems which rely on tangible or embedded interaction. Interaction may involve tangible manipulation, physical representation of data, embeddedness in real space or other forms of computationally augmenting real space. Numerous frameworks have been proposed which classify or characterize tangible systems [e.g., 3, 6, 12, 14]. However, these frameworks offer little insight about how to design tangible systems which consider user's interaction experiences [8].

The design of physical and digital aspects of tangible systems requires an understanding of the unique affordances which tangibles offer for interaction and the restrictions which children may have understanding these designed affordances. For example, while perceptual incoherence between the physical appearance and computational function of a tangible is rarely a barrier to adult users, it can be a substantial barrier to young children (Figure 4). Thus, the perceptual mappings between physical and digital aspects of tangible systems must be considered and designed with a consideration of children's age related understandings.

This classification is a first attempt to identify some of the important properties of tangible interfaces which designers must consider when designing for children and learning. The properties are proposed based on an analysis of literature in developmental cognitive psychology which sought to identify properties required or facilitated by tangible interaction where children are developmentally different than adults in terms of their cognitive skills or abilities. Each area is important because it defines a research area where little is known about how tangible interaction can support learning. Empirical evaluations and experiments with tangibles are needed to help develop design knowledge in each of these areas.

SPACE FOR ACTION

Spatiality is a property of tangible interfaces. Tangibles provide Space for Action where actions affect computation. Unlike traditional desktop systems which utilize an indirect controller, mouse and/or keyboard for input, tangible systems afford opportunities to capitalize on children's developing repertoire of physical actions and spatial abilities for direct system input and control. Theme parks and interactive exhibitions in museums, art galleries and science centers have created a rich tradition of creating environments which respond to children's (and adult's) actions and movement. However, little is known about how to design these environments specifically to support experiential learning. Design requires an understanding of how and why children's actions in space are related to cognitive developmental change [2].

Examples

Tangible interfaces provide space for small and large actions. In Anderson's 'ensemble' project, a young boy's action of opening and closing a purse style bag generates sound (Figure 1) [1]. When the bag is opened, light triggers a sensor which controls the sound output. Lund's playware tangible tiles afford opportunities for much larger actions (Figure 2) [9]. The boy runs and leaps through the air to move from one tangible sensor tile to another.

Figure 1. Space for small actions [1]

Figure 2. Space for large action [9]

PERCEPTUAL MAPPINGS

Tangibles afford various kinds of mappings between physical and digital space. Perceptual mappings refer to the mapping between the perceptual (often appearance) properties of the physical and digital aspects of the system. Design requires consideration of children's understanding of the relationships between how things appear and how things respond.

At very young ages children can quickly explore and understand the perceptual affordances of input and then watch, listen and touch to determine the output effects. Perceptual affordances are opportunities for action within the environment for individuals with suitable sensory-motor skills. They do not belong to either the environment or to the individual but to the relationships between the two. Designs which rely on perceptual affordances will allow even very young children to activate the system and subsequently explore the mappings between physical and digital aspects of the system.

Norman extended the concepts of affordances to describe opportunities for action which are created through mindful design of artificial objects and environments [11]. These designed affordances may be meaningful to adults but may not trigger intended actions in children. Thus designed affordances need to consider the age appropriate perceptual, cognitive and motor abilities and limitations of children [2].

Examples

Perceptual mappings are coherent when there is a direct correspondence between the surface or visual physical and digital properties of a tangible interface. For example, in Malzek *et al.*'s Pente tabletop game one of the physical tokens is yellow and cylindrical (Figure 3) [10]. The corresponding digital representation is also yellow. It is represented as a circle which is the 2D cross section of the cylinder. In Antle's music tunnels (Figure 4) there is an incoherent perceptual mapping between the physical and digital intended to provide opportunities for reflection. The physical appearance is that of coloured tunnels. The digital output are images and sounds which are dynamically generated based on children's actions, locations and collaborative behaviors inside the tunnels.

Figure 3. Coherent p. mapping [10]

Figure 4. Incoherent perceptual mapping [Antle]

BEHAVIORAL MAPPINGS

Behavioral mappings refer to the mapping between the input behaviors and output effect of the physical and digital aspects of the system. Design requires consideration of children's understandings of how things behave. Specifically, design of behavioral mappings requires an understanding of how children apply principles of cause and effect. Principles include those of temporal precedence, covariation and temporal and spatial contiguity. System events which do not conform to these principles may trigger confusion, disinterest or (ideally) reflection. Conversely, events which do conform to these principles contribute to ease of use for school age children.

Examples

In the mechanical building toy augmented by computation, Topobo, there is tight coupling between physical and digital behaviors (Figure 5) [7]. Topobo records and plays back movement. Input and output behaviors are similar. Both involve movement of the toy. At the other extreme, the physical and digital behaviors of the robotic dog, Aibo, seem unrelated in both time and space (Figure 6) [2]. This is in part due to the autonomous nature of Aibo. The computation which determines the output response is based on a complex summation of stored past actions in addition to current input actions. As a result, school age children (and some adults) have great difficulty applying schemata for cause and effect in order to understand the relationships between inputs and output behaviors.

Figure 5. Tight behavioral mapping [7]

Figure 6. Loose behavioral mapping [2]

SEMANTIC MAPPINGS

Semantic mappings refer to the mapping between the information carried in the physical and digital aspects of the system. Design requires consideration of children's understandings of what things mean in various representational forms.

As Uttal summarizes based on earlier work of DeLoache *et al.*, children under the age of seven may have difficulty relating physical manipulatives (one form of representation) to other forms of representation (e.g., written) across contexts [13]. This stems from the difficulty young children have appreciating that a single object can represent two different things or be seen in two different ways. The ability to understand multiple referents and representations develops slowly and individually, rather than all at once. If it is not possible to reveal semantic mappings, then children may need to use multiple representations without explicitly understanding the mappings. For example, children may physically rotate a jigsaw puzzle piece to fit either the "picture" or the "form." They can find the correct place for the piece without having to consciously choose one form of representation over the other.

Examples

The semantic mapping between physical and digital representations may be literal, analogical or metaphorical. The Tangible Shapes user study was designed to understand how the properties of tangible systems could be used to support exploration of the morphology of 3D geometric forms in ways that promote schemata development in 7 and 8 year old children. Children were asked to find matches between 2D and 3D shapes in a series of spatial visualization tasks (Figure 7). When asked to match 3D geometric shapes to 3D forms in projected images most of the children made the same mistake (Figure 8). They matched the rectangular block to a cylindrical object (Oscar's garbage can) in the image. The correct solution is the cylindrical block. The semantic mapping was not understood. The garbage can was interpreted as its 2D representation rather than its real 3D form. There was no mechanism to reveal or explore the mappings between the *multiple representations* of the same object.

Figure 7. Correct literal mapping [Antle]

Figure 8. Incorrect literal mapping [Antle]

Figure 9. Analogical semantic mapping [Courtesy of Philips]

In Philips' Entertaible demonstration, the toy taxi embedded in the block is represented analogically. The taxi is like a real taxi in that it inherits car-like properties. For example, it cannot move onto sidewalks or through buildings. However, in many ways it is unlike a car. It is small, has no engine, cannot be driven and doesn't move using wheels. Children may have more difficulty than adults understanding which properties it inherits and which it does not.

SPACE FOR FRIENDS

Tangible and spatial computer-mediated systems have both the space and the affordances for multiple users. This presents several unique opportunities. While many topics might be explored under this theme, collaboration and imitation are typical and important ways that children learn socially. Design requires an understanding of the key factors that support children's collaboration or imitation. One important factor in understanding collaboration is the degree to which the system constrains, forces or merely facilitates collaboration using age appropriate means.

Examples

In Bobick *et al.*'s KidsRoom children are constrained by the narrative to collaborate [4]. In order to get to where the wild things are, they must all row the bed together. The vision-based tracking system records their joint movements. If they do not collaborate, narrative cues encourage them to do so. In contrast, in Ferris and Bannon's cardboard box interface project collaboration between children and adults is facilitated by the design of multiple boxes [5]. It is not forced, only facilitated by the design.

CONCLUSION

Five properties of tangible interfaces which are important for the design of tangibles to support children's action based learning are presented. These are: space for action; perceptual, behavioral and semantic mapping; and space for friends. The author proposes that each property is important because children have different limitations and abilities than adults which will impact the quality of tangible interaction. Design research which attempts to build knowledge of child tangible interaction must consider both theoretical grounding and empirical experimentation in each of these areas. This is the focus of the author's ongoing work.

ACKNOWLEDGEMENTS

This research is funded by NSERC.

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