Designing Tangibles for Children
What Designers Need to Know

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Abstract
New forms of tangible and spatial child computer interaction and supporting technologies can be designed to leverage the way children develop intelligence in the world. In order to design playful learning tangibles designers must understand how children interact with and understand the representations embedded in tangible systems. In this short work in progress paper the author summarizes relevant theory from cognitive developmental psychology which may provide grounding for the design of tangibles to support children’s learning.

Keywords
Tangible interaction, embedded interaction, cognitive development, dynamic systems, learning, children.

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

Introduction
Tangible systems have a powerful ability to engage school age children in active play which promotes cognitive development. Healy provides support for
tangible, physically-based forms of child computer interaction when she states that body movements, the ability to touch, feel, manipulate and build sensory awareness of the relationships in the world is crucial to children’s cognitive development [9]. Research which explores the role of theory in designing these new forms of tangible interaction for children is needed. This work in progress paper presents a series of theoretically grounded design considerations, presented as questions, which may inform and inspire the design of tangibles for children. This paper contributes design knowledge about users of tangible systems.

Design Concepts for Tangible Interaction
Much research on tangible user interaction focuses on the design of new systems [11]. A special issue: ‘Tangible Interfaces in Perspective’ marks a shift towards research based on theoretical and conceptual understandings of tangible interaction [10]. Hornecker [11] provides a good overview of recent perspectives on tangible interaction. Zuckerman presents child-specific work on tangibles which focuses on the classification of tangible manipulatives as “Froebel-inspired” or “Montessori-inspired” [24]. Rogers et al. present a conceptual framework for mixed reality for children. It focuses on the notion of transforms between virtual and physical dimensions [18]. Marshall et al. highlight the possibility of using the distinction between “readiness-to-hand” and “presence-at-hand” in tangible user interface design to promote reflection in children [14]. The design considerations presented in this paper are a continuation of the author’s previous work which mines the rich domain of developmental psychology for theoretical concepts which can inspire and inform the design of interactive technologies for children (e.g., [1, 2]).

Children’s Cognitive Development
Cognitive development proceeds as children actively explore the physical and spatial aspects of their environment. Piaget, Gibson, Vygotsky, Dewey and Newell share an emphasis on children as active learners embedded in a physical and social environment [15]. Cognitive development involves the acquisition of organized knowledge structures called schemata.

Cognitive development also involves the gradual acquisition of strategies for remembering, understanding and solving problems [15]. DeLoache et al. have shown that even young children develop metacognitive strategies (i.e., learning about learning) [4]. These include the ability to self-regulate learning and reflect on the appropriateness of strategies. Gardner’s theory of multiple intelligences helps explain why development varies across individual children [7].

Tangibles systems can provide what Resnick calls “conceptual leverage” which enables children to learn concepts and develop schemata which might otherwise be difficult to acquire [17]. Designing these kinds of tangibles assumes child users who learn through play and engage in learning which is active, social and involves self-motivated knowledge acquisition. These assumptions mirror how children learn “in the wild” of the playground or the playroom. The challenge is to design tangible games that support playful learning and also provide age-appropriate conceptual leverage.

Cognitive Development & Tangibles
The author proposes that understanding the following three areas of cognitive development is important for the design of tangibles: embodied cognition; spatial cognition; and symbolic reasoning [2]. In addition, the perspective on children’s cognitive development which
views development as a non-linear dynamic system is interesting. Based on the theoretical grounding summarized in this paper, research may then proceed by exploring the utility of these design considerations through small empirical studies of prototypes. For example, the author is currently conducting user studies to explore ways of supporting children to visualize relationships between 3D geometric forms and their 2D representations. Observations of children cutting clay primitives to reveal sections and using flashlights to reveal silhouettes provide insight into the kinds of embodied, physical interactions and mappings between multiple representations required to build a tangible system. These user studies combined with theoretical ideas have lead to the proposal for a tangible game similar to Tetris. In the tangible version, 3D geometric blocks are placed on a table and act as system input. Blocks can be sectioned and manipulated by players to align them with a dynamically changing displayed 2D puzzle.

**Theoreticaly Grounded Design**

*Embodied Cognition*

An embodied perspective on cognition views cognition as grounded in bodily experience [16, 22, 23]. This perspective is particularly salient for children who develop new schemata through a combination of sensation, perception, action and reflection. For example, children often learn to count using their fingers and to measure using their body as a reference (e.g., “an arm’s length”). The following are related design considerations:

- How can interactions be based on the ways which children naturally solve problems using their bodies?

The perspective of embodiment also provides an understanding of how children’s ideas are organized in growing conceptual systems grounded in physical, lived reality. For example, the abstract concept of balance has several meanings including: balancing colors in a picture; balancing a checking account; and balancing a system of simultaneous equations. Each is a conceptual extension of the bodily experience of balance [12]. Children develop abstract understandings by building them on concrete bodily experiences.

- How can we leverage children’s understandings of bodily-based concepts to help them understand abstract concepts?

The interplay of action and cognition is made salient by an example from research by Funk et al.. They present empirical evidence which shows that children as young as five can successfully solve kinetic mental rotation tasks without moving their bodies. Although they do not move, they solve these tasks using both motor and cognitive processes. That is, they imagine their hands moving the object in order to solve the task [6].

- How can we support parallel (not competing) use of motor, perceptual and cognitive processes?

**The Development of Spatial Cognition**

Spatial schemata are developed prior to abstract schemata. Gattis argues that spatial schemata provide a foundation for more abstract reasoning [8]. Spatial schemata aid cognition because their familiar organizational structures can be used to facilitate memory, communication and reasoning. While the mechanisms are debated, it is clear that children use rich spatial schemata as a foundation for the development of more abstract schemata. For example,
children are often taught counting using the metaphor of counting as adding to a pile of objects.

• How can we base abstract concepts on children’s understandings of spatial concepts and relationships?

Maps are one form of symbolic representation of space. Tangible interfaces provide both a model and a control for physical space which is then mapped either directly or indirectly to virtual space. Liben provides empirical evidence that the relation between cartographic map use (i.e., use of a spatial representation) and the development of spatial cognition in children is reciprocal [13]. Children’s developing conceptions of space and mental abilities to visualize, transform and change perspective in space improves their understandings of maps. In turn, their developing conception of maps improves their ability to conceive of space and understand spatial information [20].

• How can the physical and digital aspects of tangibles be used to support reciprocal mappings between spatial and mental representations?

The Development of Symbolic Reasoning
Manipulatives are objects (e.g., rods, blocks) designed to promote development of children’s understanding of the world. Uttal summarizes that children under the age of seven may have difficulty relating physical manipulatives to other forms of representation (e.g., written) across contexts [21]. 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. Uttal also cites research that describes how allowing children to play with an object may detract from their ability to see that object as representing something other than itself. A small model of a room cannot easily be viewed or used as a map of a real room if children have played with the model. That is, when they see the small room model as an object to be played with it is difficult for them to see it also as a model of something else. This research pertains to preschool age children. However, it exemplifies how the development of symbolic reasoning proceeds slowly and individually rather than all at once.

• How can we support children to build up meaning actively through explorations of the relationships between representations and actual entities which are being represented?
• How can we make mappings between representations easily understood?

Dourish’s case for variable coupling between intentional action and effect in order to allow elements of an interactive system to take on meaning is deeply relevant for how children develop new schemata [5].

• How can we design representations to communicate how they are coupled to the world in ways that allow children to manipulate and understand multiple levels of meaning?

Development as a Non-Linear Dynamic System
Recent infant studies (e.g., [19]) suggest that development (e.g., motor and cognitive) may be understood in terms of interactions of multiple local factors, each with relatively equal importance. Factors include: bodily growth, environmental factors, brain maturation and learning. Clarke calls this approach to systems design “soft assembly” and contrasts this to systems with centralized control [3]. Development of schemata can be viewed as this kind of complex adaptive behavior which emerges from physical experience in biologically-constrained systems. Schemata development requires the ability to perturb a
system, explore misconceptions and revise thinking [23].

- How can we create a system that allows flexible interactions and intelligent adaptive responses which allow children to adapt thinking over time?
- When and how should we provide local, fast, direct, real time feedback?

Another feature of soft assembly systems is cognitive offloading through external scaffoldings. These are external aids that can include interactions with other children, adults, or aspects of the environment. For example, children (and adults) often organize tangible objects as a memory aid.

- How can tangible qualities of objects and spaces be utilized as adaptable, external aids which support the development of new understandings of schemata over time?

Conclusion
The long term goal of this work is to design tangible systems based on an understanding of why and how tangible interaction can support cognitive development in children. The paper introduces four areas of cognitive development which may be relevant for the design of tangibles systems. Specifically, this work focuses on design to support action-based knowledge acquisition through active exploration.

Concepts from embodied cognition and dynamic systems suggest that successful tangible systems will incorporate an adaptive, body-based style of interaction which leverages children’s developing and existing repertoire of physically-based actions. Acquisition will be achieved through exploration with real time feedback of how things work.

Children often develop understandings of abstract concepts based on existing understandings of body-based and spatial concepts. Thus, tangible systems might be well suited to help children develop abstract schemata. Abstract schemata related to causality, time and spatial relations may be good candidates. Each new schema can be acquired through metaphor or analogy which utilizes existing spatial schemata and physical aspects of the tangible system.

Tangible systems inherently contain multiple representations. However, children slowly develop an understanding of object and referent. Thus, the mappings between physical and digital representations must be carefully designed and communicated in ways which are explicit, flexible and can be explored by children.

These are only some of the important theoretically grounded design considerations. There will be others. Empirical user studies of children using experimental prototypes will reveal the importance and interplay of these factors as children use tangibles to help them develop new understandings of the world.

Acknowledgements
This research is funded by the Natural Science and Engineering Research Council of Canada (NSERC).

References
2. Antle, A.N. The CTI framework: Informing the design of tangible and spatial interactive systems for children, First International Conference on Tangible