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Studying children's tactile problem-solving in a digital environment

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A B S T R A C T

Given that modern children have grown up with numerous digital interactive devices it is essential to understand how the digital environment might affect children's cognitive development. As an extension of previous studies, this research investigates the cognitive effects of tactile interaction on children's problem solving. In order to explore the cognitive development of children with respect to tactile interaction, we compared furniture arrangements by elementary school students of 3D blocks and pencils. A protocol analysis was adopted for examining the ways in which children used the two different tools. The results of this study show that tactile interaction supports children's problem solving. This research implies that children in early education need to experience a wide range of digital devices utilizing rich sensorial dimensions as such devices stimulate divergent thinking, affecting cognitive developmental trajectories.

1. Introduction

In recent years, children have been using digital interactive devices for study and play. There is a current trend in digital interface development toward more natural interactions with computers as alternatives to the conventional mouse and keyboard. Much recent research into Human Computer Interaction (HCI) has explored the potential of novel interaction techniques in hybrid environments such as natural language, haptics and gesture recognition. Among the new approaches to HCI, we are specifically interested in tactile interaction combined with Augmented Reality (AR) as an interactive coupling of real objects with digital information (Azuma et al., 2001; Azuma, 1997; Dias, Santos, & Diniz, 2002). Objects' physical properties allow direct manipulation and tactile feedback, thus offering the potential to impart manual and cognitive advantages to HCI (Arias, Eden, & Fischer, 1997; Stricker, Klinker, & Reiners, 2001; Wang, Li, Huang, & Tang, 2001).

One of the authors of this article explored, from a cognitive viewpoint, the role of tactile interaction in design. It was revealed that the use of tangible interfaces changed architecture students' spatial cognition. The overall intention of this paper is to extend knowledge of how sensory rich tactile interaction plays a critical role in supporting children's constructive perception. It has been argued that rich experience of the physical is critical to children obtaining an understanding of the abstract world of semiotic systems and that emergent conceptualization in children is initially 'embedded' in sensorial interactions (Matthews & Seow, 2007). It might be expected that tactile interaction grounded in users' sensorial experiences could stimulate concept emergence, thus affecting children's problem solving processes. Given that modern children have grown up with digital interactive tools it is essential to understand how these digital interfaces affect children's cognitive development, particularly with respect to creative thinking.

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This research aims to increase understanding of children's problem solving in tactile situations, based on the distributed cognition theory, emphasizing human interaction with technical devices and artifacts (Halverson, 1994; Rogers & Ellis, 1994). We assume that affordances of tactile interaction support children's cognitive activities, thus leading to creative problem solving. We conducted experiments to compare elementary school students' use of 3D blocks with their use of sketches to carry out a design activity. We reasoned that deeper understanding of the effects of tactile interaction on children's cognition would provide a perspective from which novel interfaces could be designed to support children's educational experience. We therefore analyzed what children did and said while working on their assigned tasks, in order to explore the effects of tactile interaction on children's problem solving.

2. Creative problem solving

Children's problem solving can be understood in terms of the divergent thinking and creative design. Although 'creativity' is often defined by evaluating final products, expression of ideas can also be a useful index of creativity (Guilford, 1956; Runco & Richards, 1997); further, certain design processes can be used to define creativity since such processes have the potential to produce 'creative' artifacts (Gero, 1992; Visser, 2004).

2.1. Divergent and creative thinking

Guilford (1956) noted that creativity is closely associated with the abilities to restructure problems and reinterpret thoughts, leading to reduced 'fixedness' in developing solutions. Specifically, Guilford considered creativity to involve divergent thinking, emphasizing ideational fluency, originality, flexibility and elaboration. Ideational fluency refers to the number of relevant ideas and is a primary index of divergent thinking, while originality and flexibility relate to unusual ideas, specifically referring to the number of infrequent and uncommon ideas expressed (Chan et al., 2001; Wallach, 1985). Elaboration refers to the number of ideas developed in addition to an original concept, demonstrating a subject's ability to develop and extend upon ideas. Divergent thinking does not guarantee creative outcomes, however it has become widely used as a way to estimate the potential for creative problem solving in the educational field (Lissitz & Willhoft, 1985; Runco, Plucker, & Lin, 2000). Since it does not penalize children for their lack of expertise, divergent thinking as an index of creativity has an advantage over achievement-oriented assessments (Charles & Runco, 2001).

Derived from divergent-thinking factors in Guilford's Structure of Intellect model (Guilford, 1956), the Torrance Tests of Creative Thinking (TTCT) (Torrance, 1966) include five subscales: creative potential, fluency, originality, elaboration, abstractness of titles and resistance to premature closure. The TTCT were initially used for identifying and educating gifted children (Hebert, Cramond, Neumeister, Millar, & Silvian, 2002), but have since become the most referenced creativity test. The abstractness of titles subscale refers to the degree that a title moves beyond labeling of a picture, and is based on the idea that creativity requires abstract thought. The resistance to premature closure subscale assesses the extent of psychological openness and is based on the belief that creative behavior requires an 'open mind' that considers a variety of information. A measure of flexibility, featured in the original TTCT, was subsequently eliminated from the TTCT because it correlated highly with the ideational fluency subscale (Hebert et al., 2002). The TTCT can be seen as providing groundwork for scaling of creativity, which can then be increased through practice (Childs, 2003).

2.2. The creative design process

While searching a 'satisficing' solution, designers often reach a key creative design concept through exploring visuo-spatial features of external representations (Archer, 1984; Gero, 1992; Suwa, Purcell, & Gero, 1999). Epistemic actions, tightly coupling action and perception, can be considered to be 'exploratory actions' (Fitzmaurice, 1996). In chess, the player expecting epistemic action moves pieces around to candidate positions in order to assess their own possible moves and possible counter-moves by an opponent, even when the player has no clear specific goal (Fitzmaurice & Buxto, 1997; Gibson, 1962; Kirsh & Maglio, 1994). Designers use epistemic actions to exploit external representations rather than to mentally compute design moves, thus generating multiple alternative representations. Multiple representations encourage designers to produce 'reinterpretations', thus preventing fixation on a single representation (Gero & Damski, 1997; Gero & Kelly, 2005; Gero & Yan, 1993; Jun & Gero, 1997). In a similar fashion, hand movements are related to cognitive processing; Kirsh and Maglio (1994) found that task completion times and error rates were reduced when subjects' hands were used in a 'coin-counting' experiment; computational actions can be performed mentally, but pointing or touching actions using fingers might play an additional valuable role in task performance.

The 'creative design process' can be characterized as ill-defined problem solving (Visser, 2004), and this is closely associated with the concept of restructuring to produce appropriate design outcomes. As underlying cognitive aspects of creative problem solving, the notions of 'problem-finding' and 'co-evolution' (Cross & Dorst, 1999; Gero, 1992; Suwa, Gero, & Purcell, 2000) are considered here. When some design specifications are not provided at the initial stage of a project, new functional issues emerge during design and these can be regarded as new design requirements (Suwa et al., 2000). Creative design can be modeled in terms of co-evolution of problem and solution spaces (Cross & Dorst, 1999). Co-evolutionary design is an approach to problem solving which is characterized by transition between 'problem' and 'solution' spaces (Maher, Poon, &