Supporting Children's Creativity through Tangible User Interfaces

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CHI 2011, May 7–12, 2011, Vancouver, BC, Canada.
ACM 978-1-4503-0268-5/11/05.

Abstract
We outline a preliminary research approach intended to explore the potential of tangible user interfaces (TUI's) in supporting children's creative problem solving activities, specifically those requiring the generation of divergent solutions. Our approach is grounded in theoretical notions taken from psychology, neuroscience, and developmental cognition. We detail a TUI currently in development called the Invention Workbench, and summarize how theoretical considerations have shaped the design of the interface.

Keywords
Tangible user interface, mental imagery, creativity support, divergent thinking, children's interfaces.

ACM Classification Keywords
H5.2. User Interfaces: Input devices and strategies, J.4 Social and behavioral sciences.

General Terms
Design, Human factors.

Introduction

Creative thinking has been identified as a critical and under-developed component of children's education. Although children are usually thought of as extremely imaginative and creative, research from developmental psychology suggests that as children age their ability to generate creative solutions diminishes. As they enter their elementary school years (about age 7) they begin to interpret objects primarily in terms of their intended use [3]. This decrease in ability to think of divergent uses is called functional fixedness [4]. The (re)development of divergent thinking skills requires children to overcome this type of rigidity in thinking.

Divergent thinking [8] is a creativity construct that describes the mental process of generating multiple solutions to a problem. It is one of the skills required for creative problem solving in a variety of fields (e.g. science, engineering, design, art), and has been shown to correlate with "real-world" creativity [16, 10].

According to a constructivist account of learning, the development of creative thinking skills can be enhanced by opportunities for a child to engage in problem solving with both physical and symbolic materials [11]. Tangible user interfaces (TUI's) [18] offer opportunities to link physical and digital (symbolic) representations and objects in ways that may support divergent thinking skills.

This paper outlines the initial stages of a research design suitable for investigating the impact of TUI's on divergent thinking in children. Previous HCI research into creativity-support interfaces has primarily consisted of frameworks based on combining theoretical approaches [13], groupware [5, 21, 9], and language used in describing creativity [1]. Our specific focus on the mental process of divergent thinking in children contributes a unique approach to HCI creativity research.

Background

Human creative behavior is a complex (and sometimes mysticized) phenomena that may at first seem to defy detailed empirical study. However, there is a long history of investigation into creativity which can be leveraged to design and evaluate creativity-support interfaces. Psychological research in particular provides insight into the mental processes that underlie creative behavior. Several psychological instruments are used to measure divergent thinking, including the widely-used Alternate Uses Task (AUT) [2] and the Torrance Tests of Creative Thinking (TTCT) [17]. These instruments quantify divergent thinking performance along several sub-scales, allowing quantitative analysis to be performed on the outcomes of creativity tasks. Subscales shared by both tests include:

- Originality – a quantification of how often a creative response occurs among the total body of test responses. This is usually measured against other responses within an experimental batch.
- Categorical Distinctiveness or Flexibility - a count of how many different categories of use a participant's responses belong to.
- Fluency – a count of total number of valid creative responses a participant provides.

Divergent thinking tasks like the AUT have also been used to examine the neuro-cognitive activity involved in creative thinking [6]. Findings from this line of research suggest that physical movement boosts creative performance in previously unexpected ways [14].

Research into mental imagery is important to consider when designing for creativity support and enhancement. Long-standing research recognizes that humans exhibit notable creative behavior without external representation or augmentation to support our thinking [7], however, more recent research suggests that these creative behaviors benefit from external representations (such as sketches) when participants have been trained to use them appropriately [19]. This suggests that external representations (like sketches) may be leveraged to further boost creative performance.

The combination of previous research into divergent thinking, tangible user interfaces, and mental imagery provides a rich base to build creativity support research on. The following research design is an initial attempt to combine these bodies of knowledge to further our understanding of how to design interfaces that support and boost creativity.

Research Design

Our proposed research approach is primarily based on the mental imagery tasks outlined in [7, 19] and [15]. Our goal is to match our task as closely as possible to previous creativity research while accounting for the unique needs and capabilities of children. Specifically, we plan to examine the creative performance of children given a creative ideation and combination task in three conditions: without the aid of external representations (i.e. using mental imagery only), with un-augmented physical objects, and with a custom TUI creativity system called the Invention Workbench.

Child participants will be given three objects randomly picked from an object list (included in the appendix) and asked to combine these objects to create a new invention. They will be told they can take as long as they need [20], and that they should tell the task facilitator when their invention is ready. After finishing their invention, they will be asked to tell the facilitator the name of the invention, how the three objects fit together, and what the invention is used for.

In the mental imagery condition the task is administered without the aid of external representation. Participants will be shown drawings of the objects they are to invent with, and asked to use their imagination to generate the invention. In the un-augmented physical object condition, participants will be given wooden or plastic versions of the preliminary objects to manipulate while creating their invention. In both conditions, after the participant describes their invention, the facilitator will sketch the invention according to the participant’s description, and the participant will label parts of their invention with the aid of the sketch.

While using the Invention Workbench, participants will be provided with physical models of the preliminary objects that are linked to virtual 3d models of the objects shown on the Workbench display. The virtual models will mimic the position and rotation of the physical objects provided to the participant, while also allowing the participant to scale and intersect the virtual objects using simple gestures. Once the participant has completed their invention, the facilitator will lock the virtual objects in their current configuration and use the virtual model to complete the naming, description and labeling portion of the task. In all three conditions the purpose of naming, describing, and labeling the invention is to elicit evidence of divergent thinking and breaking functional fixedness. In the mental imagery and un-augmented object conditions the sketch is needed to provide a visual record of the participant's invention for labeling and for post-task analysis. The Invention Workbench system facilitates this without the need for a post-invention sketch. Facilitators for the mental imagery and un-augmented object conditions will be trained to focus only on depicting the participant's description during the sketching process in order to minimize facilitator influence on the participant's response as much as possible.

Inventions from all three conditions will be rated for originality and categorical distinctiveness, while the individually labeled parts of the inventions will also be rated for originality and categorical distinctiveness, as well as fluency (i.e. the number of times a part is labeled as something other than the original name of object used to create that part). These scores may then be compared statistically between conditions to look for differences in creative performance.

Interface Design

The Invention Workbench will consist of a vertical display (at least 22" diagonal) and a set of physical objects which are tracked as they are moved and rotated. The tracking data is linked to the position and rotation of similar virtual objects shown on the display. The virtual objects can also be scaled by performing an intentional up/down gesture with one hand (up is bigger, down is smaller), and intersected by firmly knocking two physical objects together. The tracking data from the physical objects is ignored when the user has completed their invention and the facilitator has pressed a key to stop the virtual objects from moving.

The Invention Workbench is designed to augment children's creativity while retaining important similarities with the non-augmented and mental imagery versions of the invention task, in order to facilitate valid comparisons between conditions. We expect the Invention Workbench to augment the invention task in two important ways: first, by offloading the *reconfiguration* process from mental imagery to an external representation; and second, by encouraging bimanual interaction and other lateralized body movements

Reconfiguration is the discovery of new forms or patterns in the combination of two known objects. Although extensive research has shown that humans can combine two known objects to create a new distinct object using mental imagery alone [7], it is difficult to recognize emergent aspects of the new object created through this process [19]. The classic example of this phenomenon is the triangle test: imagine two isosceles triangles of the same size placed on top of each other and centered to each other, one pointing upwards, the other pointing downwards. What new shape emerges at their intersection? Most people can find the diamond that emerges from this combination using mental imagery alone, but have difficulty recognizing the two parallelograms that emerge as well [12]. (Sketch this out for yourself to see the parallelograms.) In this case, sketching the two triangles offloads the imagery, allowing for a reconfigured reading of the new combined form. It is hoped that the interactive virtual object models displayed by the Invention Workbench will offload the combination of the objects in a similar way, allowing for greater recognition of new reconfigured objects than with mental imagery or non-augment objects alone.

Bilateral body movement has been shown to positively affect divergent thinking performance on the AUT. For example, in [14] a statistically significant boost in originality and categorical distinctiveness was observed among strong-handed participants who performed a bilateral eye movement exercise (i.e. moving the eyes back and forth horizontally in sync) before completing the AUT. By affording bimanual interaction with the physical objects tracked by the Invention Workbench, a similar boost in these divergent thinking sub-scores may be observable.

The Invention Workbench draws from a subset of geometric primitives used in mental imagery research [7]. Objects with common names and uses that are most likely familiar to children were chosen in order to make more explicit any mental changes in function when evaluating participant inventions. For example, a child will most likely associate a ball with certain functions (like playing games), but if they use the ball/sphere as a robot head in their invention, there is clear evidence of breaking functional fixedness and generating alternate uses for the ball.

Future Work

Currently, several import issues of this research design remain to be solved. First, robust and affordable real-time position and rotation tracking in an appropriate physical form factor presents a non-trivial technical challenge. Second, some important aspects of the research design have yet to be determined, including whether the sessions are run within or between participants, the length of task sessions, number of allowed task repetitions, and demographic profile of the participants. It is likely that the final details of these factors will depend on the partnering institution used to facilitate access to child participants (e.g. a public science centre vs. a charter school). Appropriate verbal pre-tests are also being investigated. A verbal pre-test would establish a verbal ability baseline before children participate in the task and aide in separating verbal skill from creative performance.

Summary

This paper outlines the foundations of a unique line of inquiry into the potential of TUI's as creativity support tools for children. By building upon research from a variety of research areas, we hope to gain a clearer understanding of the effects of tangible interaction on cognition, while also encouraging the combination of psychological research and measurement tools with HCI practices to further the empirical evaluation of interface design in general.

Appendix

Preliminary objects for the invention task:

Ball (sphere)	Hook	Can (cylinder)
Box (cube)	Handle	Ring (torus)
Wheels	Stick	

Acknowledgements

This research was supported by the Social Sciences and Humanities Research Council. The authors also wish to thank Dr. Alyssa Wise for her support with this research.

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