Gesture in the Crossroads of HCI and Creative Cognition

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ABSTRACT

Investigations of gesture in HCI research seek to enable usable and intuitive gesture-based interactive technology. Investigations of gesture in cognitive science seek to understand the role of gesture in thinking, language, and learning. The crossroads remains largely open, because designing for gesture interaction largely focuses on advancing device usability, and cognitive studies of gesture largely focus on advancing explanatory theory. The intersection is not a clearly defined research area, and methods that serve one focus do not necessarily serve the other. Moreover, gesture research in HCI and cognitive science each seeks to understand how gesture affects human performance, but neither discipline can predict how to do so. We approach this crossroads by focusing on research whose results contribute to an understanding of how gesture-based interaction changes cognition. We present a research program in which we look for evidence that an increase in gesturing with a tangible user interface while thinking about word combinations increases the creativity of the results. Broader implications of this research seek to cultivate the research area and engender new theory.

Author Keywords

Gesture; embodied cognition; design cognition; experimental design

ACM Classification Keywords

H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

General Terms

Human Factors; Design; Measurement.

INTRODUCTION

We are conducting research in the crossroads of HCI and cognitive science by focusing on how gesture-based interaction changes cognition. We selected tangible computing for this focus because it is a technology that enables gestures with handheld interactive objects. Here the term gesture, broadly-construed, encompasses body or hand movements including interactions with technology. Gesture is a kind action, which is linked with language, but has a separate ability to carry meaning not exclusively for communication; it is a way of thinking with our hands [15, 18]. Other actions are not intrinsically linked with language. Both gesture and action have wide ranging roles in HCI research. We adopt the term gesture in a broader sense, which includes hand movements when using tangible devices, because unlike prescribed actions afforded by some gesture interfaces, tangibles can be held in hand when performing gestures, actions, or both. Tangible user interfaces (TUI) are the coupling of physical objects and digital information, and eliminates the distinction between input and output devices [12,30]. For example, Figure 1 illustrates TUIs with children using Sifteo™ cubes. TUIs offer a dramatic shift from pointing and typing to grasping, holding, and arranging.

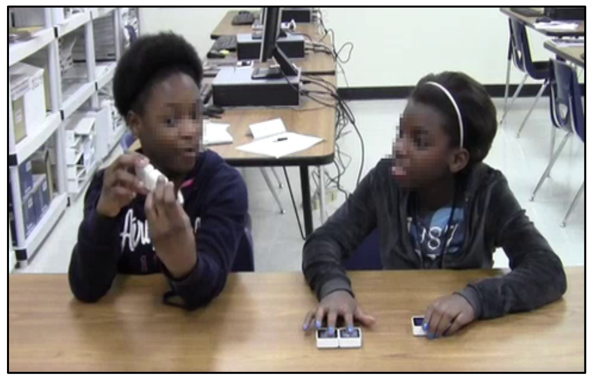

Figure 1 TUIs: Children using Sifteo™ cubes to make creative word combinations; each cube displayed one word.

HCI and design research link creativity with gesture

A special issue on the role of gesture in designing [31] provides an overview of how gesture is used in design and how TUIs affect and build on our use of gesture [17]. Marshall [24] developed a framework for research on TUI's and learning from a design research perspective. One study of the role of tangible interaction and gesture found that, for the same task, when participants used TUIs compared to keyboard and mouse, they focused on cognitive aspects of the task associated with creativity [9].

We propose that interfaces based on physical objects (i.e., TUIs) may offer more opportunities for epistemic (i.e., exploratory) actions than pragmatic (i.e., direct) actions. Epistemic actions are exploratory motor activity aimed at uncovering information that is hard to compute mentally. For example, novice chess players move pieces around to candidate positions to mentally explore possible moves and counter-moves. Epistemic actions offload some internal cognitive resources onto the external world by using physical actions. In contrast, pragmatic actions are motor activities directly aimed at a final goal. For example, experienced chess players are able to first set a mental goal then perform the minimal motor actions to reach the goal [12,14,20]. Direct mental goals typically do not require exploration. However, creative thinking is exploratory as its

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goals are insufficiently well-defined [28]. Using TUIs is correlated with changes in designer's thinking: Kim and Maher [19] showed an increase in epistemic actions and, through protocol analysis, observed an increase in cognitive processes typically associated with creative design.

Most studies on TUIs have been undertaken from a HCI technology viewpoint, which aims to describe fundamental technical issues and evaluate usability of prototypes. While many researchers have argued that TUIs improve spatial cognition, there has been insufficient empirical evidence to support the claim [13,21,22]. We adopt TUIs for the specific purpose of studying how bodily movement affects creative thinking, by intersecting HCI methods with empirical experimental science, and developing that crossroads approach is itself a dimension of our research.

Cognitive Science finds gesture affects cognition

Evidence from cognitive science finds actions with our hands affect thinking. Recent research on gesture and thought [1,3,4,5,6,8,9,10] has shown that gestures are an aid for thinking and not exclusively an aid for communication.

Gesturing aids learning. Goldin-Meadow et at. [16] found that children learned a strategy for solving math problems if they imitated a teacher's gestures, When instructed to imitate a teacher's gestures, Goldin-Meadow et al. [16] found that those children learned a strategy for solving math problems compared to children who did not gesture. For example, while teaching children to solve math problems such as "6 + 3 + 5 = _ + 5" the instructor made gestures indicating a grouping strategy. Placing a V-hand under the "6 + 3" then pointing to the blank indicated the strategy of grouping 6 and 3 then putting the sum in the blank. Observing and mimicking hand movements that reflected the grouping strategy led to the formation of knowledge about that strategy. The "V" gestures were metaphorical because they indicated mental groupings where no explicit groups were marked, and mental movement where no numbers physically moved across the equal sign. Goldin-Meadow and Beilock [15] summarized these and related findings as, "gesture influences thought by linking it to action", "producing gesture changes thought" and can "create new knowledge" (pp. 667-8). These effects may build on the role of gesturing in cognitive development. When children are learning to count, touching physical objects facilitates learning [1,5].

Gesturing aids creative problem solving. Kessell and Tversky [18] found that when people are solving and then explaining spatial insight problems, gesturing facilitates finding solutions. Similarly, gesturing helps people recall and maintain abstract conceptual themes: Preventing gesture altogether reduces the use of spatial metaphors in speech [4]. Gestures do not merely enable access to words, they enable mental access to metaphorical concepts. For example, people consistently made upwardly gestures while telling a story about feeling "up" (i.e., happy) even when they described downward spatial aspects of a scene [6]. When the storytelling task was paired with moving marbles upwards or downwards, storytelling was disrupted when the movements were inconsistent with the story's theme and recall was improved when making thematically consistent movements [6]. These results suggest that physical motions are linked to creativity, metaphor and abstract thinking.

Gesture and embodied cognition

The crossroads of gesture in HCI and cognitive science invites a confluence of theory, and theories of embodied cognition are most germane to our focus. Embodied cognition offers explanations of empirical results in which bodily states and actions affect thinking [2,29]. Even mental simulations of bodily positions can affect thinking. Palmer, Clausner and Kellman [7,26,27] designed air traffic displays with the aim of improving visual search by graphically encoding altitude in 2D displays as icon size and contrast. Two metaphors were tested: larger-darker is higher altitude, and smaller-lighter is higher altitude. Interpreting the altitude of aircraft icons depended on whether participants imagined displays as viewed from above or below. Participants were instructed in one of two conditions: bodily looking head up or head down at instructional displays. Afterward in the visual search task participants looked straight ahead at desktop displays but were asked to imagine them from the perspective in which they had been instructed. Search performance was better when imagining displays from above than from below. The results found an imagined perspective effect consistent with embodied theories of cognition. Moreover, theory served a dual role in the research. Display design was guided by theories of metaphor and visual perception; experimental results contributed to theories of embodied cognition. That is, the research was both theory-grounded and theory-building. HCI has widely embraced embodied cognition theories (as well as others, e.g., [17,25]) for guiding design research, while empirical science is largely theory-building.

In the crossroads of cognitive science and HCI research our investigation is both theory-grounded and theory-building. Whether our results are consistent with embodied cognition theories, or alternative theories is itself a matter of our investigation. To these ends, our research is enabling us to design methods of analysis and experiments to observe children using TUIs during a creative cognition task. We have chosen to study children because our research has a potentially broad impact on cognitive development and on promoting creative thinking with educational technology.

EXPLORATION IN AN HCI DESIGN PERSPECTIVE

We initially explored how children use TUIs by observing play and design sessions [23]. We applied protocol analysis and the KidsTeam co-design methodology which includes children as active partners in design research [12,13].

Seven children aged 7 to 12 years were assigned to work in three groups of 2, 2, and 3 children each. Each group played one of thee different Sifteo™ games, which varied in the kinds of cognitive skill required: a math puzzle, a spatial tiles puzzle, and a resource sharing game. We video recorded the children using the tangible cubes.

The process of coding the video data revealed a fundamental methodological challenge arising from our joint perspective for both HCI and cognitive considerations on these data. There was a need to categorize multiple children interacting with multiple cubes, in multiple modes of communication, in multiple spatial locations. Each child talked, gestured, and played with the cubes, and interacted socially. Each cube displayed texts and pictures, emitted sounds, and sensed actions. Play resulted in actions on cubes that cubes were designed to sense, and ones they were not. Cubes stood in relationships with other cubes. Spatial relationships dynamically evolved in child-child, child-cube, and cube-cube combinations. Simultaneous actions compounded the challenge. For example, in one group a boy and girl played on the floor with three cubes. In the span of only six seconds a boy held a cube in his left hand while he pointed at a cube resting on the floor, touched its display, while a girl grasped a third cube with both hands, put it on the floor, neighbored one of its sides to the side of the cube the boy was touching, then rotated her cube 90º, and neighbored that side, lifted the cube off the floor, then touched its display. Theses actions included holding, pointing, touching, putting down, picking up, rotating, and interpersonal coordination.

In developing a coding scheme for analyzing, these data we considered both technology-centered and human-centered approaches, which yielded schemes of contrasting usefulness. A cube-centric perspective resulted in a combinatorial explosion of cube actions, per cube, per hand, per person, in combination with speech and other gestures. A behavioral perspective yielded a simple set of coding categories. We contribute this human-centric coding scheme for analyzing groups of people using tangible computing devices (Table 1). We use the term “action on cube” to distinguish gestures directed to a TUI from other gestures. This scheme is not limited to cube-sensed actions supported by a specific TUI design. The simplicity of the behavioral perspective is not an artifact of its generality, but because it represents a human-centered point of view on the interactions among humans and devices. This observation highlights the issues in an analysis of data at the intersection of HCI and cognitive science.

Table 1 Coding Scheme Categories

- Action on Cube
  - Cube-Sensed (e.g., press, neighbor, flip, shake, tilt)
  - Not Sensed (e.g., rotate, stack, pick up, put down, arrange, grasp)
- Gesture
  - Hand gesture (e.g. pointing)
  - Non-hand gesture (e.g. head nod)
- Audible Communication
  - Child speech
  - Child-directed sounds emitted by TUI
- Interpersonal action exchanged between children

The purpose of coding schemes and experimental designs in HCI research is to explore and enable technology design, and often introduce confounding variables without demanding rigid reductionism. Investigating cognitive effects of using technology, however, has a scientific basis in cognitive science, which demands more rigorous experiments. We are exploring this methodological crossroads.

EXPERIMENTAL DESIGN

Focusing on gesture with TUIs is enabling us to design novel experiments that meet another challenge of working in the crossroads of two areas: how to vary affordances while holding stimulus parameters constant. We met this challenge by rigorously designing experimental and control conditions that differ in selected physical and perceptual attributes, but not in the task-relevant information they display.

Two hypotheses are the focus of this experiment. 1. Tangible interaction increases the quantity and creative quality of new ideas. 2. Tangible interaction encourages spatial and metaphorical thinking. The creativity task we chose for testing these hypotheses was conceptual combination/blending [32]. Given a set of words children combined words and invented creative meanings. Stimuli were designed to promote creative thinking.

Word Stimuli: We designed two word sets consisting of six words each, matched on a variety of task-relevant psycholinguistic properties, e.g., all words were nouns about familiar objects. Within each set, there were no pairs of words that formed familiar compounds (e.g., cow, boy)

Display Design: We designed the TUI displays and poster paper stimuli to match on a variety of perceptual attributes: font size, cube/square size, and spatial layout (Figure 3).

Method and Procedure

Forty 6th grade children (aged 11-12) from a local middle school participated in our study. Children were randomly placed into 20 pairs. Working in pairs was intended to promote talking and gesturing, while still encouraging focus on the task. In the control condition, the children were seated at a table with a poster paper on which six stimulus words were printed (Figure 2 & 3). In the tangible condition, the children were seated at a table with six Sifteo cubes, each displaying a single word (Figure 1). Each pair of children participated in both conditions.

The experimental design was within-subjects and the stimuli were counterbalanced such that each group saw words displayed with similar visual form in two contrasting conditions. This allowed us to contrast tangible and non-tangible affordances for the same creative cognition task while keeping the stimuli as constant as possible.

Initial Observations

Data analysis is work-in-progress: we are applying our coding scheme in preparation for testing our hypotheses. We developed a set of observations that will guide our coding and analysis of the protocol data in two categories: verbal responses and gesture responses.

Verbal Responses: Each pair of children generally repeated a three-stage response pattern: searching for word combinations, verbally responding by saying the words, then explaining their response by describing their creative idea. Though not instructed to do so, children tended to describe the meanings of their selected combinations with word-relation-word series in the form:

$$\texttt{Word}_1\texttt{-Relation}_1\texttt{-Word}_2, \ldots \texttt{Relation}_i\texttt{-Word}_{i+1} \ldots \texttt{Relation}_n\texttt{-Word}_n \text{ , where } 2 \leq n \leq 6$$

For example, a four-word selection, *bee-shirt-rope-desk* was explained as, "A bee that wears a shirt made of ropes who sits at a desk eating rice in a car." A particularly creative example was the two-word selection *shoe-cow* explained as "A cow that is obsessed with shoes."

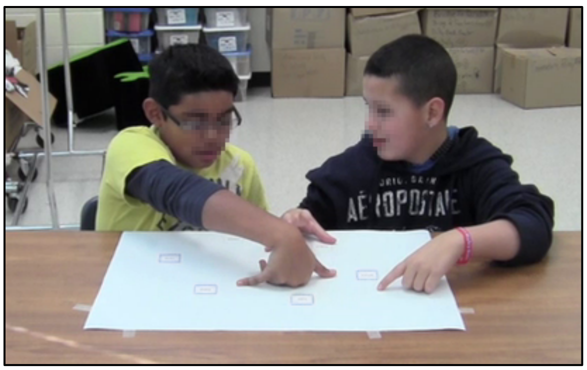

Figure 2 Control Condition: Children using words printed on a poster to make creative word combinations.

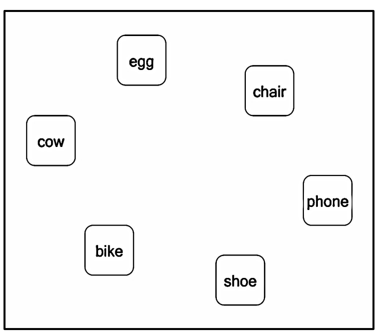

Figure 3 Poster word stimuli matched TUIs.

Gesture Responses: In the control (paper) condition gestures were largely restricted to pointing gestures. In contrast, in the TUI condition children arranged cubes into arrays of pairs and triples, while sorting through two-word and three-word combinations or linear arrays of six words in preparation of (or while) verbally reporting word combinations. TUIs promoted creative gestures, e.g., a child held three cubes representing his three-word response as he demonstrated that two of the cubes, one stacked on the other, represented the relation "happens at the same time". This use of space to express times is metaphorical.

Beyond applying our coding scheme to the experimental data for testing our hypotheses this research confronts evaluation of creativity, and investigates gestures as creative exploratory actions (i.e., epistemic gestures).

HYPOTHESES IN THE CROSSROADS

Our initial research both showcases the difficulty of confronting variables that confound experimental method when studying human interactions with technologies, and provides directions for refining our approach. At this stage in our methodological crossroads, there is significant value in hypothesis generation.

Empirical science typically proceeds by formulating hypotheses testable against expected results in un-confounded ideal conditions. HCI research typically proceeds toward developing design principles, undeterred by confounding variables. In the crossroads of HCI and cognitive science we are finding statements emerging from design-guided HCI research questions, and simultaneously refining them toward testable experimental hypotheses. We propose the following preliminary hypotheses about tangible interaction and creative cognition:

Tangible interaction...

1. facilitates epistemic gestures and actions.
2. encourages thinking about non-spatial / abstract concepts.
3. encourages greater bodily movement beyond that necessary to interact.
4. encourages more spatial and metaphorical thinking.
5. enhances creative cognition.
6. serves to offload cognition as tactile, visual, and spatial representation of working memory, and as externalization of cognitive processes.

SUMMARY AND FUTURE WORK

Our initial protocol study, the resulting coding scheme, and our experimental design represent progress thus far on cultivating a theory-grounded research area. We aim to engender new methods and build new theory in the crossroads of HCI and cognitive science. These initial studies are raising questions about confounding variables, measurement, and other methodological challenges unique to the intersection of HCI and cognitive science. The challenge is not merely a tug-of-war between research paradigms in technology design and experimental science, or where on a spectrum to select a method. Our preliminary results inform new directions for blending methodologies, from which we expect will emerge new methods, results, and theory. Our research program is revealing the essential value in bringing together HCI design and cognitive science for conducting research in the crossroads.

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