

# Designing to Support Reasoned Imagination through Embodied Metaphor

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## ABSTRACT

Supporting users' reasoned imagination in sense making during interaction with tangible and embedded computation involves supporting the application of their existing mental schemata in understanding new forms of interaction. Recent studies that include an embodied metaphor in the interaction model, which relates action-based inputs to digital outputs, have provided evidence that this approach is beneficial. Yet the design of such systems has been difficult and full of setbacks. Wide spread adoption of this approach requires a better understanding of how to design such embodied metaphor-based interactional models. We analyze three recent design-based research studies in which we have been involved in order to derive design knowledge that may inform others. Following a case study methodology we identify kernels or points in the design process where discontinuities between predicted and actual interaction highlight important design knowledge.

## Author Keywords

Embodied interaction, metaphor, image schema, reasoned imagination, interactive environments, tangibles, embedded computation, design knowledge, case study.

## ACM Classification Keywords

H.5 [Information interfaces and presentation]: User Interfaces--Theory and methods.

## General Terms

Theory, Design.

## INTRODUCTION

*"Imagination is central to human meaning and rationality for the simple reason that what we can experience and cognize as meaningful, and how we can reason about it, are both dependent on structures of imagination that make our experience what it is. On this view, meaning is not situated solely in propositions; instead, it permeates our embodied, spatial, temporal, culturally formed, and value-laden understanding."* ([17] p. 172).

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From the experientialist perspective, metaphor is a matter of imaginative rationality. Reason involves categorization, entailment, and inference. Imagination, involves, among other things, seeing one kind of thing in terms of another kind of thing, what Lakoff and Johnson have called metaphorical thought [18]. Metaphor is thus imaginative rationality. It permits an understanding of one kind of experience in terms of another, creating coherences by imposing gestalts that are structured by experience. As computation increasingly becomes embedded in everyday objects and environments it becomes important to understand how to design interfaces that support users to enact appropriate input actions and understand the relationships between these actions and digitally mediated output responses. How will users make sense of their interaction with tangible objects, interactive surfaces and interactive environments? Following from Johnson's theory of imagination, we suggest that one of the ways that users will make sense of new forms of interaction is through reasoned imagination using metaphorical interpretation.

While various authors (e.g., [3, 16, 22]) have suggested the potential value of using embodied metaphors in user interface designs to support users' reasoned imagination, there is scant empirical evidence which supports or refutes such claims [5]. In order to conduct user studies to search for evidence of benefit, we require the design of computational objects, surfaces and environments that utilize embodied metaphors in their interaction models. An interaction model is the mapping layer that relates input actions to changes in state of the computer system which may then be represented as changes in displayed images and sounds. The design of such models requires knowledge of how to incorporate embodied metaphors in non-traditional and non-graphical user interaction and user interfaces. Without this knowledge the design of such systems requires many cycles of iteration, experimentation and tradeoffs which result in lengthy design processes and unexpected setbacks. Previous work in this area has revealed some of the complexities of designing to support users' reasoned imagination and difficulties in understanding users' interactions with such environments [6].

This paper addresses the question: How can embodied metaphors inform the design of tangibles and interactive

environments which support users' reasoned imagination? If we do not know how to design these kinds of embedded user interfaces based on embodied metaphor theory, then we cannot investigate them empirically in the lab or field. We addressed this question through a case study analysis of a series of our design-based research projects: Sound Maker [3, 5], Moving Sounds Tangibles (MoSo) [7] and Springboard [4, 13]. By revisiting and reflecting on these three design-based research processes involving embodied interactional models we identified common kernels or points in the design process where discontinuities between expected and actual interaction highlight important principles for successful designs [1]. Through analysis of the conditions around these kernels and the consequences that flowed from them we are able to articulate and ground reflections in empirical evidence [8]. We generalize across cases to move beyond the specifics of each case and enhance credibility [21]. The results of our analysis are articulated as bits of design knowledge. These are intended to speak to design practitioners and researchers interested in embodied interaction and to perhaps peak the interest of those who have not yet been exposed to these theoretical ideas made real through design.

## BACKGROUND

### Reasoned Imagination

Johnson argues for an extended notion of imagination [17]. He concurs with the nineteenth-century view that imagination connotes creativity, invention and artistic expression. However, he makes the case that imagination also plays a critical role in human reasoning and understanding. Imagination involves the human capacity to organize mental representations into meaningful, coherent unities that are comprehensible. Johnson presents compelling evidence that embodied or image-schematic structures are metaphorically extended to direct and constrain people's networks of meanings. These acts are ones of reasoned imagination and are used to creatively structure reasoning about novel concepts, perceptions and experiences.

In presenting his theory of reasoned imagination Johnson breaks away from the deeply rooted dichotomies that have dominated Western philosophical thought. Reason and imagination are not separate; they are integrated and integral to human understanding. A rich perspective on rationality involves and depends on structures of imagination including embodied metaphors. "*Once we no longer demand a disembodied (or nonphysical) rationality, then there is no particular reason to exclude embodied imagination from the bounds of reason.*"([17] p. 168).

### Embodied Metaphor Theory

Embodied metaphor theory provides the theoretical foundation for a non-objectivist account of meaning and the integration of reason and imagination in human meaning

making [17]. It seeks to explain the ways in which human understandings of perceptual experiences and abstract concepts rely on metaphorical extensions of embodied schemata. It has been suggested to provide an important foundation for the design of interfaces that rely on natural movements because it relates schemata level understandings of bodily experiences with more complex perceptual and conceptual structures that humans use to understand and interpret their interactions with the world [5, 16].

A metaphor is the interaction between a target domain and a source domain that involves an interaction of schemata and concepts. Johnson claims that metaphors arise unconsciously from experiential gestalts relating to the body's movements, orientation in space, and its interaction with objects [17]. He called these fundamental gestalts image, or embodied, schemata, based on their bodily origins. Embodied metaphors extend embodied schemata to structure and organize abstract concepts. For example, we develop an understanding of the idea of balance as well as the process of balancing through our early interactions with the world such as learning to walk, balancing a tray and balancing on a sea-saw or teeter-totter (Figure 1). We use the resulting schema to structure our understanding of balance in more abstract domains such as justice (e.g., The punishment *balanced* the crime.), psychology (e.g., His reaction was *unbalanced*.) and mathematics (e.g., The equation was *balanced*.).

### Embodied Metaphor in Interaction Design

The three projects discussed in this paper are grounded in the theory of embodied metaphor. Each had the goal of creating computational environments that supported reasoned imagination. Our working hypothesis is that an interaction model that relates schema-based inputs to metaphorically related output responses will support users to transfer reasoning structure from the schema domain to the digital domain. The result will be learning, performance and experiential benefits based on the metaphorical projection of embodied knowledge.

## THE SYSTEMS

We begin by briefly describing three research prototypes. Each was designed to support reasoned imagination through an embodied metaphor-based interaction model. Each was created using a design-based research approach. The intended user groups for two of the projects include both children (aged 7 to 10) and adults, with slight variations in content as appropriate. The MoSo tangible object prototypes were designed specifically for children (aged 7 to 9). These research projects provide the core material for our case based analysis. Between them, they represent variations in interface style (tangible object, interactive

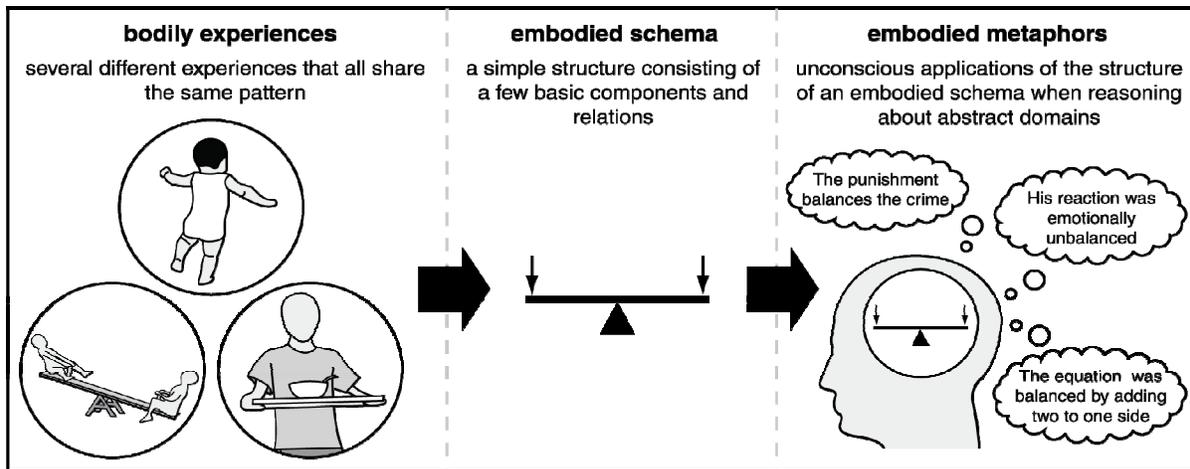


Figure 1. Embodied schema and metaphorically related concepts of balance.

room), purpose of sound feedback (guide interaction, represent concepts), modalities of representations (sound only, images and sounds) and digitally represented concept domains (sound, justice). The similarities in design goals and process combined with variations in interaction, information and modalities support generalization beyond the specifics of a single design case. Although two studies are still underway, each has been documented in the human-computer interaction literature [4, 5, 7]. As background, we offer a brief overview of the research goals associated with each and summarize the key interactional and design features of each system.

### Sound Maker Interactive Audio Environment

The Sound Maker is an interactive musical sound making environment [5, 6]. The interaction model instantiated the metaphor, *music is physical movement*. Several schemata related to physical movement are projected through metaphor to structure understanding of sound parameters. For example, the metaphor *tempo is the speed of body movement* maps speed over time to speed over distance. The metaphor, *rhythmic sound is smooth movement*, maps regularities in beats over time to smoothness of movements over time.

The system is implemented using a camera vision system to track user's movements in an empty rectilinear space (see Figure 2). The system relates qualities of movement to changes in percussive audio output. Users control the sequencing of percussive sounds and the change of musical parameters of those sounds through their collaborative body movements in the space. The system tracks users' *speed* (i.e., rate of change of user position), the amount of *activity* in their movements (e.g., waving arms, stomping feet versus walking stiffly), the relative position or *proximity* of each user in the space (e.g., moving closer together versus farther apart), and the *flow* of their movements (e.g., synchronous/smooth versus asynchronous/choppy). Speed and activity can be distinguished by the following example. When a high

level of activity occurs and the participant is standing in one place (e.g., running on the spot), the speed is zero since speed is defined as the rate of change of position (in any direction).



Figure 2. Two versions of the Sound Maker system.

The sensor data are mapped to four musical parameters of four sequence players. The musical parameters that are controlled by body movement are volume, tempo, pitch and rhythm. Each sequencer has a unique percussive sound (marimba, celesta, pizzicato viola and woodblock) and is associated with one section of the sensing area. The data generated in each sensing section affects that sequencer's output. More information and video samples can be found at [www.antle.iat.sfu.ca/EmbodiedMetaphor](http://www.antle.iat.sfu.ca/EmbodiedMetaphor).

### Moving Sounds Tangibles

The Moving Sounds Tangibles (MoSo) project was conceived to build on and extend the Sound Maker project by designing and evaluating hand-sized tangible sound making objects [7]. The objects were designed to produce sound changes for sound parameters (e.g., volume, tempo, pitch, rhythm) when moved appropriately. For example, the object in Figure 3 on the left was designed to afford rotational movement which is easily varied from slow to fast. This results in corresponding changes in the sound's tempo. The object on the right affords fast or slow movements through shaking. The speed of the up and down movement resulted in changes to the tempo of sound.

The objects were designed based on a formative enactment study. In this enactment user study we looked

for evidence of different metaphors associated with sound changes by searching for repeated patterns of schematic type movements in a series of sound-movement exercises. The results of this study were used to design the final set of objects to ensure that the metaphorical interaction models were grounded in empirical evidence as well as relevant theoretical work.

The MoSo project allowed us to experimentally explore the same issues as in Sound Maker but using hand actions with tangible objects rather than whole body interaction. In addition, we studied the use of multiple metaphors for each sound concept since qualitative findings from earlier work indicated that users often used more than one metaphor to understand the same concept [3].



Figure 3. Moving sound tangible objects.

### Springboard Interactive Environment

The Springboard environment was developed in order to validate and duplicate findings from the two previous studies, extend our work to visual as well as auditory modalities and extend our work to very abstract concepts. The concept of balance in social justice is such an abstract and value-laden concept [4]. Social justice can be defined as the balanced or equitable distribution of the advantages and disadvantages within a society. Springboard supports users to interactively explore and reason about representations related to three social justice issues: the distribution of food; the resources used for shelter and community control and safety. Each issue involves consideration of many factors. We simplify each issue to the consideration of two main factors which when balanced result in an equitable or socially fair solution.

There are several schemata related to our experiences of balance [17]. However the twin-pan balance schema is often used to conceptualize justice in legal and social domains (Figure 1). For example, the scales representing the twin-pan balance schema are often associated with Greek statues of Athena, goddess of war and justice. Similarly, modern legal buildings are adorned with the scales symbol.

The system is implemented using a camera vision system to track user's movements in an empty, black rectilinear space. The active input space is a raised platform made from a crib mattress spring, board and black cloth. When a user steps onto the platform, their centre of gravity becomes immediately, slightly out of balance since they will likely wobble on the platform. By moving left or right on the rectangular platform, the user can also be out

of balance spatially. States of bodily balance are determined as users move their body's centre of gravity and spatial position on the platform. Users' movements in and out of balance trigger metaphorically related changes in the image and sound displays. For example, an out of balance body state triggers images of mono-culture (too little variation) and food dumping (too much production) as show in Figure 4 (left). Figure 4 (right) shows an earlier screen design with a vertical layout where an imbalanced body states triggers images of fast food restaurants contrasted with images of starvation and environmental degradation (top to bottom). Sound feedback also reflects input states as described in [13].



Figure 4. Springboard: sample design layouts.

### METHODOLOGY

We use case analysis to search for commonalities in the design-based research approach to the development of the three research instruments described above.

#### Design-Based Research

Design-based research was put forward with the expectation that researchers would systematically vary aspects of the design context so that each variation would serve as a type of experimentation that allowed researchers to both test and generate theory in naturalistic settings [8]. It provides researchers with a methodological toolkit designed to search for evidence of learning benefit related to the intervention called design experiments [8, 11]. A design-based research approach shares similarities with formative design evaluations. However, it is the focus on incorporating existing theory into design interventions, testing theory and potentially generating new theories that distinguishes it from formative evaluations. Our goals are to incorporate embodied metaphor theory into our interaction model, test our theory in context and potentially generate new theories about embodied metaphor in the context of interactive environments. These are the primary reason we adopted a design-based approach rather than an iterative design and formative evaluation approach.

#### Case Study Methodology

Design-based research supports a case based analysis approach because it reveals major turning points in the design process. These turning points often occur as a result of design-based experiments where parameters in the design are systematically varied based on theoretically grounded expectations. This allows us to both identify important design considerations but also to build design

theory based on the systematic exploration of theories of embodiment through design.

The case based analysis of our design-based research processes involved the identification of a sequence of major turning points in the process, which we refer to as “kernels” [1]. We also identified the set of situational consequences which flowed from these kernels. Kernels are often the result of moments in design activities where we realized that what we intended was not what we or users either enacted or interpreted. As such these moments reveal critical information about the ways in which embodied metaphors may be used successfully in interaction design. Identification of kernels forms the foundation for the generation of specific design solutions and more general principles about how embodied metaphor theory can inform interaction design. In this way we view the design platform as a context through which theory can be advanced [8].

Both design-based research and case based research are often described using a narrative approach. Narrative has been historically used as a method to convey a series of related plot points (i.e., kernels) which unfold over time. We adopt this approach mindful of the central subject problem.

#### **Credibility and Transferability**

Critics of design-based research have raised concerns about credibility and trustworthiness [8]. For example, the issue of researcher bias in selecting evidence, reporting observations and developing trustworthy claims cannot be ignored. In our work we address this problem in three ways. First, we have involved researchers with different disciplinary backgrounds in each of our project teams. For example, in Springboard, we had an experimental scientist, a phenomenologist, practice-based designer and a social scientist on our team. This triangulation supports credibility through identification of common observations and interpretations (e.g., of kernels) that are not tied to one world view. Second, in our analysis we searched for similarities, differences and generalizations between the three projects as a method of validation and in order to make *petite generalizations* beyond the specifics of each design context [21]. Thirdly, we incorporate member checking into our design experiments to ensure that we have interpreted participants’ behaviors and verbalizations in ways that reflect their own interpretations. We also suggest that the contribution of our work should be judged by its usefulness, called consequential validity [12]. One step in ensuring consequential validity is to frame findings in ways that can be flexibly used by others. We have done this through the articulation of guidelines which can be adapted based on different design or user experience goals, rather than presenting rigid prescriptive rules.

## **DESIGN**

### **Design Challenges**

Some of the difficulties of designing systems which have embodied metaphorical interaction models follow from the following points:

- Since metaphors are processed unconsciously, it can be difficult to identify the appropriate metaphors involved in the design of a computational system or set of representations;
- For the same reason, it can be difficult to determine the embodied schemata that underlie each metaphor;
- Invisible interfaces do not inherently afford or constrain any particular action that the user should effect, as noted by Bellotti *et al.* [9]
- There may be ambiguities in sensing and interpreting input actions to match a specific schema;
- It is difficult to know which aspects of the interface a schema should be directly applied to (e.g., input actions, sound feedback, visual layout) and which it should be metaphorically applied to (e.g., image content, sound content) and how to represent the schema in each case;
- There may be more than one way to map or relate schematic input actions to metaphorical output states.

### **Design Requirements**

Our main objective for all three projects was to create working prototypes that we could use as research instruments to look for evidence that leveraging embodied knowledge to support reasoned imagination had performance, learning and/or experiential benefits.

For each project a major design goal was that input actions had to be sensed, the resulting data interpreted in light of particular schema, and then used to control metaphorically related digital representations. A secondary design goal was that each interaction model had to be easily customizable in order to relate different sets of input actions to output responses. This was necessary to vary the interaction model during design experiments and later comparative experiments with the completed prototypes. A third goal was that the interaction should support the user to both move and think without privileging one modality more than the other. For example, changes in output images and sounds should be fairly easy to perceive and interpret while enacting input movements.

### **Design Framework**

As is characteristic of most design-based research the design process was closely informed by both an orienting theoretical perspective (embodied metaphor theory) and a design framework. The design framework detailed the various dimensions of the interactive environment which required coherent application of schema and related metaphor(s). The design framework included five major dimensions which were iteratively designed, explored systematically, integrated, and refined to eventually produce a unified whole: (1) bodily enactment; (2) spatial

enactment (3) auditory representation and perception; (4) visual layout and perception; (5) conceptual system representation and interpretation.

Each project began with the identification of appropriate schema and metaphor by reviewing both rational and empirical research on metaphor. For each metaphor, the target domain schema was identified and articulated through both written and diagrammatic accounts (see Figure 1). We explored how each schema might be instantiated in bodily, spatial, visual and auditory modalities. We also explored how the metaphorically related conceptual systems would be digitally represented.

Input spaces were designed by applying schematic ideas to initial designs. This was followed by iterations of body storming to understand felt experiences of bodily and spatial schemata interspersed with technical experimentation with camera tracking and analysis of system fidelity with respect to recognizing input actions based on various schemata. We call a set of actions based on a specific mental schema an *enactment*. Design experiments were used to inform input space design. The goal was to create affordances and constraints that supported users to enact a set of schematically based input actions. For example, in Springboard, a wobbly input platform resulted in users moving their centre of gravity in and out of balance as they moved. The spring platform supports users to enact both balance and imbalance as they interact with the system.

Display dimensions were designed to support specific auditory and visual perceptions based on schemata. Literature searches on the use of schemata in the perception of auditory representations produced little guidance. We turned to design experiments to test users' interpretations of various sound changes, and to illicit enactments of preset sound changes (as described in [7, 13]).

Springboard required a visual layout based on a schema. We experimented with several twin-pan layouts. For example, we positioned the images as if they were people seated on either end of the teeter-totter and had the system move the images up and down in response to input actions. We also experimented with including a silhouette of the user in the centre of a teeter-totter with images at each end. However, using moving images and situating the user in the display both proved to be distracting. These strategies resulted in users focusing their attention almost exclusively on the screen rather than on their bodies.

The sound content (Sound Maker, MoSo) and image content (Springboard) were selected to be representative of the core concepts and to form a coherent conceptual system. For example, the selection of visual representations (i.e., photographs) of issues in social justice were determined based on results of brainstorming "weight" factors for each depiction; sourcing images based on preset rules; conducting group sorting exercises to reach inter-subjective agreement on weights associated with each

image and numeric state of balance associated with it. Images were placed in bins according to their weights, and selected for display according to the composite balance index based on a moving window of sensed input data.

Understanding user actions, enactments, reactions, perceptions, conceptual understandings, reasoning and interpretation were critical throughout the design process. Kernels were identified when users (either ourselves or study participants) responded to the system in unanticipated or unexpected ways which indicated that either the schema or metaphor was being interpreted in a way that did not fit with our theoretical expectations and related design goals. For example, when users' tried to play the three vertical displays (Figure 4 right) like a slot machine (e.g., trying to get an image of a chicken in each screen for the food distribution theme) we realized that while users were definitely using their imagination, they were not using their reasoned imagination based on the balance embodied schema. At this point we realized that the balance schema should be incorporated into the visual display layout to constrain interpretation (Figure 4 left). It is these moments which strongly inform our design guidelines.

## THE KERNELS

We identify five main kernels; important turning points which have situational consequences [1]. Each kernel was found in at least two of the three projects. A turning point is composed of four aspects. The first aspect is when our theoretical understandings created certain *expectations* in terms of action, interaction or interpretation. The second aspect was when we saw a pattern in which users' did something quite *unexpected*. The third aspect involved one or more *design experiments* designed to investigate the issue further; and the fourth aspect was our synthesis of *what was learned* which may include mention of theoretical or empirical support. Each kernel resulted in significant changes to our systems. We describe each below and articulate them further in guidelines in the following section.

### Which metaphor(s)?

*Expected:* Based on our interpretation of Johnson's work (e.g., [17] Chapter 6), we focused on a single, dominant metaphor for each concept represented in the system. We expected that by including a single metaphor for each relation in the interaction model, that users' would enact inputs and reason with and about the system using that metaphor in ways that provided ease of use, performance and experiential benefits.

*Unexpected:* We found in every study, that for situations like new forms of interaction with computational systems, participants rarely utilized a single, privileged metaphor. They used a battery of metaphors, schemata, and non-metaphorical interpretations as they worked to understand and use each system. We found this even when a single metaphor was clearly the dominant way a concept is

typically understood (e.g., tempo as speed). However, users are resourceful in their enactment of various schemata and interpretation through related metaphors as they come to understand new forms of interaction and reason about digital content.

For example, in early design sessions with Sound Maker, we experienced both children's and adults' behaviors and verbalizations which indicated that they were using more than one metaphor in their interpretation of the system's sound changes. An early design used a cross shaped design which resulted in users enacting an in/out/containment schema (see Figure 2 left). Users would move around the circle made by the cross's circumference and in doing so would move in and out of the active sensing areas of the arms of the cross. We also saw evidence of the in/out schema in Springboard as users tried to control the system by stepping on and off the platform. For both systems we chose a single metaphor for each concept represented in the system. However, users reasoned about both the system itself and one or more abstract concepts represented in the system using multiple metaphors and a variety of reasoned imagination strategies.

*Design Experiments:* In the Sound Maker design process we used a literature analysis of metaphor and music, interviews with experts and pilot studies to determine and validate our metaphorical interaction model. Based on our unexpected findings (above) we conducted a design experiment in the MoSo project. It was created to explicitly elicit evidence of different metaphors which might be associated with changes in sound parameters (described in [7]). We compared full body movements to hand movements on an object (a plastic ring) to simulate similar environments to the ones we were designing for MoSo and had designed in Sound Maker. We asked children individually and in groups to enact sound changes for a variety of sound concepts (e.g., pitch, volume, tempo, rhythm, harmony, timbre, articulation). Through coding of movements associated with each type of sound change, we were able to find evidence of schemata and corresponding metaphors in their movements. Findings suggested that users did use more than one metaphor to interpret some sound concepts. Some sound concepts had a dominant metaphor (e.g., tempo) and others had several which were enacted with relatively equal frequency (e.g., volume, pitch). Others were not enacted through metaphor at all (e.g., timbre). We were also able to eliminate mappings which were suggested by literature or experts but we did not observe (e.g., articulation). The result was the design of three sound objects, each with a different metaphor, for each sound parameter.

*What Was Learned:* The first step in the design process is often the identification and analysis of the metaphor and schema which will form the basis for interaction design. This may be initiated through an analysis of language and literature to identify candidate metaphors. However, we

suggest that creating an early design experiment in which participants are exposed to variations of a mocked up or working versions of the system and samples of content which will be used in the conceptual reasoning system in order to observe and identify what metaphors they enact in the actual context of the system. This kind of experiment is invaluable in understanding which metaphors will be used in interpretation in the context of the computational system; in revealing multiple metaphors; and in identifying dominant metaphors if they exist. Depending on the goals for the system, the system can then be designed around single or multiple metaphors.

### **Space before Bodies**

*Expected:* We expected that users' would initially use a body-based metaphor in their reasoning since these schemata are the first to develop starting in vitro, and thus have a neural primacy.

*Unexpected:* Users' routinely interpreted input spaces designed to afford bodily schemata (e.g., moving in and out of balance; moving quickly and slowly) as spatial structures (e.g., moving along edges, in and out of corners). There was clear evidence in their actions, exploratory patterns and verbalizations that they had a spatial view on the input space and were using spatial schema (e.g., up-down; in-out) to reason about the system. For example, in Sound Maker many verbalizations showed a focus on where the sounds were located or triggered ("Here its low.") rather than focusing on how to make sounds ("When I move this way, it gets lower."). In early Springboard user studies we also saw this effect. Users routinely stepped on and off the platform in their exploration of the system. Interviews with participants revealed that participants were rarely aware of the ways that they moved their bodies but were often aware of their spatial exploration strategies.

*Design Experiments:* In the Sound Maker design process, we changed the shape of the sensed input space from a cross to a rectangle to reduce movements in and out of the space and to simplify the shape by reducing corners and edges. We also moved the speakers out of the corners and back from the active floor area. We observed fewer spatial behaviors and heard fewer spatial interpretations, but spatial interpretations remained dominant. In the Springboard design process, we ran sessions where participants used the system with and without the platform. With the platform removed and no boundaries marked on the floor, users oriented less to the space. However, they were often confused when they moved beyond the active sensing area and the system responded in unexpected ways. In the MoSo design experiment, users enacted both spatial and movement based metaphors depending on the sound parameter. We note that spatial interpretation was more evident for interactive environments than for tangible objects. This finding supports the notion that objects may afford different schemata and related interpretations than

interactive spaces. However, this idea remains to be fully explored.

*What was Learned:* Without unambiguous affordances, users' interpret a new interactive object or environment in terms of its spatial properties before they interpret interaction in terms of their body movements. That is, spatial schemata are privileged over body-based schemata in interpretation. In TUIs, interaction is interpreted both through reference to spatial and movement schemata depending on context. However, primary schema such as in-out and up-down were enacted in all systems. This observation finds support in research that investigates the contribution of spatial schemata in abstract thought. It is in line with Hummel and Holyoak's findings that spatial schemata are heavily involved in reasoning through transitive inference and Gattis' suggestion that spatial schema are involved in understanding all types of relations (as discussed in [14]).

#### **Unanticipated Actions**

*Expected:* We expected that users' would enact each particular schema in one or more common ways. For example, that they would change their speed in a rectilinear space by running faster or slower, or that they would move in and out of balance from a standing position.

*Unexpected:* Users surprised us with the many ways they could enact a particular schema through movement. In Springboard we saw users move their bodies in and out of balance standing, sitting, on their knees and lying down on their fronts, sides or backs. They did so quickly or slowly, discretely or continuously. We observed a tendency for users to move up and down, followed by left and right. We also discovered that sometimes they don't move at all and simply wait for the system to respond. Our observations about users' tendencies to move in certain directions are in line with Tvyersky *et al.*'s research. They suggest that the body has three essential axes: that formed by head and feet; by front and back; and by left and right. They found empirical evidence that when the body is upright, the characteristics of the body and the world work together to make the head-feet axis most accessible; followed by left-right; and lastly front-back [23].

*Design Experiments:* The MoSo design experiment reported in [7] was designed specifically to explore and analyze the myriad ways of enacting schema related to sound changes. We saw many ways of moving self or an object using a slow-fast schema. The schema was enacted with the waving of limbs, shaking the body, running on the spot, running around a room, rotation or translation of objects, to name a few. We conducted a similar study for balance, challenging participants to enact different balance movements, again looking for common aspects of movement that could be sensed. We decided on balance and imbalance of their centre of gravity over their feet which could be sensed through a blob tracking algorithm. This approach enabled sensing of many ways that users

moved their bodies, each resulting in their centre of gravity being in or out of balance.

*What was Learned:* With invisible interfaces users will move in myriad ways or not at all. While Benford *et al.* suggest that "The physical form of an interface fundamentally shapes the kinds of interactions that users can and will perform" [10], we suggest that invisible interfaces such as an empty room or simple everyday objects can be used in more ways than can ever be expected. Thus, we proposed in [3] that the design of an input space or object must afford the *discovery* of particular actions which share common qualities which can be sensed. This can be achieved through the combination of affording and constraining the input space or object (e.g., building a platform in an otherwise empty room). It is also necessary to provide salient and easily perceivable feedback related to the affect of movements [3]. Another strategy is providing task oriented cues which supported users to enact or eliminate particular movements from their repertoire. A combination of task and design strategies works well to support users to develop accurate mental models of an interaction model.

#### **Alternative Interpretations**

*Expected:* We expected that users would come to a single, coherent understanding of the interaction model and the concepts represented digitally through metaphorical projection of the inferential aspects of the input domain to the system domain.

*Unexpected:* In the Sound Maker studies we found that users who encountered system artifacts sometimes formed their interpretation of the system relying on these artifacts, and ignoring contrary evidence. We also saw alternative (and incorrect) interpretations due to a system bug in an early version of Springboard. In this case users failed to see the relationship between their body actions and changing image content. Instead they interpreted the apparently random content in the vertical display based on prototypical categories (e.g., people, food, houses). *Design Experiments:* In Springboard we conducted a series of experiments designed to severely constrain users' interpretations. Our initial design focused on sensing users' balance (schema) as a system input, and only varying the amount of balance depicted in the images. However, in order to constrain users' interpretations to the schema and ideas about balance (versus other interpretations of the images), we designed both sound feedback and the visual layout to reflect the twin-pan balance schema. For example, we replaced ideas of using sound as representational content (associated with the "sounds" of social justice) and instead used it as system feedback structured using the twin-pan schema. Sound feedback was structured with two factors associated with each side of the platform (timbre, pitch). Depending on the location of the user, each sound parameter would change to produce feedback that was perceived as in or out of balance. We also replaced the

vertical images in the display with two side-by-side image frames (Figure 4). Each frame represented a factor or weight in the twin pan schema. By highly structuring the sound feedback and display layout using the schema, participants were more readily able to interpret the system using the twin-pan schema. We observed that users more quickly and more easily understood the relation between moving their bodies in and out of balance and the changes in image content.

*What was Learned:* Humans are extremely versatile interpreters. They can easily come to interpretations of a system which are either unexpected or inaccurate. Others have made similar comments (e.g., [15]). Users seem to be anxious to construct a model of the system. As a result, any correlation between their action and the system's response will draw their attention. Unless they notice a contradiction, they will continue to expand on their first interpretation. For this reason the system needs to be as stable as possible and design should try to account for misinterpretations through corrective feedback.

If a specific interpretation is desired, then we suggest that the combination of structured tasks with schematically structured environments and salient confirmatory feedback are required to channel imaginative reasoning into a single, unified interpretation. However, we suggest that there may be many instances when this is not desirable; that openness to interpretation may be a crucial part of the experience.

#### **Balancing Experiential and Reflective Cognition**

*Expected:* We expected that users would move fluidly between experiential and reflective cognition [19] using a form of reflection-in-action [20] as they explored and experimented with our systems.

*Unexpected:* What we observed was that users tended to either think or move. Doing both at the same time seemed to take a lot more effort. This was particularly true when pairs of participants were using a system. In Sound Maker, pairs of users had to stop to talk and so they couldn't easily build on what they had discovered through movement. This resulted in pairs of users planning their approaches in advance and then carrying it through.

*Design Experiments:* In the input design of Springboard we found through body storming that input movements that were too taxing resulted in a complete focus on movement with little cognitive effort available for thinking. We see this as analogous to learning to ride a bike. Conversely, when input actions were extremely simple (e.g., waving), we found that our focus was almost exclusively on the images. There was no awareness of body movement. The latter may not be problematic since many schemata are enacted without conscious attention. While the former may be sufficient to use the system, it will not support the necessary "diving-in and stepping-out" required for reaching deeper understanding of system contents [2].

*What was Learned:* In order to support users to both act and reflect, we suggest that it is important to design support

in the system for how people are going to act and also for how they are going to think. If learning to use a system through intuitive action is all that is required, supporting reflection-in-action through embodied metaphor may be sufficient. However, if developing a deeper understanding of system content is the goal, then consideration should be given to how the system allows the user to disengage or step out to reflect on their interpretations.

#### **DESIGN KNOWLEDGE**

We provide a summary of lessons learned in the form of generalizable design knowledge. Each is meant to guide design depending on the goals and specific context of the design problem. For example, the same knowledge may be applied differently if the goal is to tightly constrain a single interpretation or to remain open to interpretation.

1. Most conceptual systems are understood through several embodied metaphors and often extend one or more primary schemata (e.g., up-down, in-out).
2. Users' enactments of schemata and their metaphorical reasoning depend on both the content and context of the computation system.
3. Users' tend to reason about an embedded interactive system using spatial schema to structure physical exploration and subsequent imaginative reasoning.
4. Designing an input space to confine input actions to a schema-specific set requires consideration of actions that are *discoverable* based on consideration of the order of directions which users' tend to move; designing physical affordances and constraints in the space; providing task-related cues; and ensuring salient, immediate feedback.
5. Designing a system to support specific interpretations based on imaginative reasoning requires the use of the primary schema(s) in as many channels as possible (action affordances, multimodal feedback; layout; representational content) a stable error tolerant system; and salient feedback.
6. For users to deeply understand and reason about abstract concepts requires support for both reflection-in-action (tacit knowledge) and a stepping out or disengagement in order to reflect more deeply on experience and reflect consciously on interpretations.

As designers move through the trajectory of the design process they may come to points where these bits of knowledge are relevant. Our aim is to support generation of design alternatives, guide the selection of design solutions and inform design of user studies. How each knowledge bit is used depends on the design and research goals. For example, if the goal is a specific interpretation to support either usability (ease of learning) or learning (understanding specific concepts), then it is important to tightly afford and constrain input actions and resulting interpretations. Conversely, if the goal is to create an open-ended experience, such as an art installation, then designers may intentionally not constrain the system but may sense

multiple input schemata. In this way, this knowledge is not prescriptive but generative and provides guidance depending on the design context.

## CONCLUSIONS

While theories abound, there is little empirically generated design knowledge about how embodied metaphors can be used to support user's reasoned imagination in learning to use and using embedded computational systems. This paper contributes theoretically grounded and empirically derived knowledge through the case based analysis of kernels, or turning points, in the design process where theoretical expectations did not match empirical findings. Our overall design research in embodied interaction serves to produce instruments for ongoing empirical investigations and also knowledge about how to incorporate embodied metaphor theory into the design of such artifacts.

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## REFERENCES

1. Abbott, A. (1992) What do cases need? Some notes on activity in sociological analysis. In Ragin, C.C. & Becker, H.S. (eds.) *What is a Case? Exploring the Foundation of Social Inquiry*, Cambridge University Press, Cambridge, UK, 53-82.
2. Ackermann, E. (1996) Perspective-taking and object construction: Two keys to learning. In Kafai, Y. & Resnick, M. (eds.) *Constructionism in Practice: Designing, Thinking, and Learning in a Digital World*, Lawrence Erlbaum, Mahwah, NJ, USA, 25-35.
3. Antle, A.N., Corness, G. and Droumeva, M. (2009) Human-Computer-Intuition? Exploring the cognitive basis for intuition in embodied Interaction. *International Journal of Arts and Technology*, 2 (3), forthcoming.
4. Antle, A.N., Corness, G. and Droumeva, M. (2009) Springboard: Exploring embodiment, balance and social justice. In *Extended Abstracts of CHI 2009*, ACM Press, 3961-3966.
5. Antle, A.N., Corness, G. and Droumeva, M. (2009) What the body knows: Exploring the benefits of embodied metaphors in hybrid physical digital environments. *Interacting with Computers*, 21 (1-2), 66 - 75.
6. Antle, A.N., Droumeva, M. and Corness, G. (2008) Playing with The Sound Maker: Do embodied metaphors help children learn? *IDC 2008*, ACM Press, New York, NY, USA, 178-185.
7. Bakker, S., Antle, A.N. and van den Hoven, E. (2009) Identifying embodied metaphors in children's sound-action mappings. *IDC 2009*, ACM Press, New York, NY, USA, 140-149.
8. Barab, S. and Squire, K. (2004) Design-based research: Putting a stake in the ground. *The Journal of the Learning Sciences*, 13 (1), 1-14.
9. Bellotti, V., Back, M., Edwards, W., Grinter, R., Henderson, A. and Lopes, C. (2002) Making sense of sensing systems: Five questions for designers and researchers. *CHI 2002*, ACM Press, New York, NY, USA, 415-422.
10. Benford, S., Gaver, B., Boucher, A., Walker, B., Pennington, S., Schmidt, A., Gellersen, H., Steed, A., Schnädelbach, H. and Koleva, B. (2005) Expected, sensed, and desired: A framework for designing sensing-based interaction. *ACM Transactions on Computer-Human Interaction*, 12 (1), 3-30.
11. Brown, A.L. (1992) Design experiments: Theoretical and methodological challenges in creating complex interventions in classroom settings. *The Journal of the Learning Sciences*, 2 (2). 141-148.
12. Dewey, J. (1938) *Logic, the Theory of Inquiry*. Holt and Co., New York, USA.
13. Droumeva, M., Antle, A.N., Corness, G. and Bevans, A. (2009) Springboard: Exploring embodied metaphor in the design of sound feedback for physical responsive environments. *ICAD 2009*, available at <http://icad.org/node/3059>.
14. Gattis, M. (2001) *Spatial Schemas and Abstract Thought*, Bradford Books, Cambridge, MA, USA.
15. Gaver, W., Beaver, J. and Benford, S. (2003) Ambiguity as a resource for design. *CHI 2003*, ACM Press, New York, NY, USA, 233-240.
16. Hurtienne, J., Weber, K. and Blessing, L. (2008) Prior Experience and Intuitive Use: Image Schemas in User Centred Design. In P. Langdon, P.J.C., & P. Robinson (eds.) *Designing Inclusive Futures*, Springer, London, UK, 107-116.
17. Johnson, M. (1987) *The Body in the Mind: The Bodily Basis of Meaning, Imagination, and Reason*. University of Chicago Press, Chicago, IL, USA.
18. Lakoff, G. and Johnson, M. (1980) *Metaphors We Live By*. Chicago Press, Chicago, IL, USA.
19. Norman, D.A. (1993) *Things That Make Us Smart*. Basic Books, New York, NY, USA.
20. Schön, D.A. (1983) *The Reflective Practitioner*. Basic Books, New York, NY, USA.
21. Stake, R. (1995) *The Art of Case Study Research*. Sage, Thousand Oaks, CA, USA.
22. Svanæs, D. and Verplank, W. (2000) In search of metaphors for tangible user interfaces. *DARE 2000*, ACM Press, New York, NY, USA, 121-129.
23. Tvyersky, B., Bauer Morrison, J., Franklin, N. and Bryant, D., J. (1999) Three spaces of spatial cognition. *The Professional Geographer*, 51 (4), 516-524.