Playing with The Sound Maker: Do Embodied Metaphors Help Children Learn?

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ABSTRACT
In this paper we present the results of a comparative study that explores the potential benefits of using embodied interaction to help children, aged 7 to 10, learn abstract concepts related to musical sounds. Forty children learned to create musical sound sequences using an interactive sound making environment. Half the children used a version of the system that instantiated a body-based metaphor in the mapping layer connecting body movements to output sounds. The remaining children used a version of the same environment that did not instantiate a metaphor in the mapping layer. In general, children were able to more accurately demonstrate sound sequences in the embodied metaphor based system version. However, we observed that children often resorted to spatial rather than body-based metaphors and that the mapping must be easily discoverable as well as metaphorical to provide benefit.

Author Keywords
Embodied interaction, embodied schema, metaphor, interactive environments, tangibles, music, sound, children.

ACM Classification Keywords
H5.2. User interfaces: theory and methods.

INTRODUCTION

> "It is not enough to say that the mind is embodied; one must say how." (Edelman 1992, p.15) in [9])

What does an embodied view of cognition mean for interaction design for children? Dourish popularized the term *embodied interaction* in the human computer interaction community. He used the term to describe an approach to interaction design that placed an emphasis on understanding and incorporating our relationship with the world around us, both physical and social, into the design and use of interactive systems [5]. Philosophically, the approach is based on a phenomenological paradigm that emphasizes the role of action and perception in meaning making. Knowledge is gained through purposeful and engaged practical actions in the world around us. Rohrer offers a broad survey of the literature on embodiment [24]. He describes a dozen different uses of the term. For the purposes of this paper, we use embodied interaction in its practical sense to denote direct, body-based interaction with computation embedded into common everyday artifacts such as objects and spaces.

Several emerging classes of interfaces rely on embodied interaction. For example, one of the defining features of tangible and embedded interfaces, as broadly defined by Hornecker & Buur [12], is the link between direct action based input and digitally mediated output. Recently, the embodied nature of tangible user interfaces has been of interest to designers of children's educational technologies [3,19,26]. This interest is predicated on the view, common in education, that learning with physical manipulatives may be beneficial (e.g., Montessori Method, Frobel's Gifts) [23,29]. However, there is little empirical evidence to date to support such claims in the realm of tangible and embedded interactive technologies. Like most new fields, early work has focused on technical development, taxonomic descriptions and theoretical frameworks. Moving the field forward requires research that explores the application of theoretical ideas in concrete designs and empirical studies that systematically investigate the claimed benefits of such designs. The research described in this paper addresses the need for empirical studies that investigate how and why embodied forms of interaction in interactive environments might enhance children's conceptual learning.

The perspective of embodiment provides an understanding of how children's ideas are organized in growing conceptual systems grounded in physical, lived reality [3]. In this research we look to the actual mechanisms utilized in embodied cognition and aim to support these in design. Extending claims made by proponents of hands-on learning, we investigate if children benefit from physically based interaction in learning abstract concepts in an interactive environment. Lakoff and Johnston propose that many abstract concepts derive meaning through the cognitive mechanism of extending embodied schemas through conceptual metaphor [18]. Antle suggests that designs that leverage these kinds of embodied metaphors may benefit children's learning [2]. Antle also proposes

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that suitable learning domains include those that involve abstract concepts that are understood through physical or spatial metaphors [3]. One such domain is that of music. Features of musical sounds (e.g., amplitude, tempo and pitch) can be understood through a variety of movement-based physical metaphors [14]. In addition, musical concepts are commonly taught to school age children and interactive music systems for children are increasingly common. Taken together, these factors suggest that music is a suitable test domain. While it may be easy to suggest leveraging conceptual metaphor as a design strategy the devil is in the details.

In this paper we provide a description of The Sound Maker, an interactive musical sound making environment that was designed to leverage an embodied metaphor in the mapping layer that relates input actions to output responses. We describe the results from an empirical experiment with forty children, aged 7 to 10 that was designed to examine the utility of this approach. The experiment was conceived to look for evidence of learning benefit by measuring children's performance and experience using an interactive musical sound environment that utilized an embodied metaphor in the mapping layer compared to children's performance and experience with the same environment that did not utilize an embodied metaphor in the mapping layer. We conclude the paper with a discussion of observed themes relevant to the design of embodied tangible learning technologies for children.

RELATED WORK

Embodied Interaction, Children and Learning

There are a number of ways that an embodied approach to interaction in interactive environments might benefit children's learning. For the purposes of research focus, we can make a useful conceptual distinction between the social and physical aspects of embodied interaction, although in practice the two are inseparably intertwined. Augmented environments that support children's participation, collaboration and social interaction have received much attention. However, augmented environments that support direct physical manipulation have received considerably less *empirical* attention and it is here that we focus our research. For those interested, O'Malley and Stanton provide an excellent overview of both aspects of learning with tangible technologies [21].

Interactive Music Systems for Children

Several researchers have recently explored aspects of interactive musical environment for children. Zigelbaum *et al.* describe BodyBeats, a suite of three whole-body electrical musical interfaces for children designed to help children recognize, mimic and create patterns [28]. Birchfield *et al.* describe SMALLab, a student centered video and audio learning environment, based on active and exploratory learning approaches [4]. Anderson created a suite of sound augmented dress-p objects and observed how children interacted with them in order to better understand their naïve understandings of sensors [1]. Ferris and Bannon created the cardboard box interface, a sound installation designed to stimulate discovery, play and adventure among children [8]. Droumeva *et al.* examined an alternative continuous, graduated (versus discrete) approach to sound feedback in the design of responsive environments for children [6]. There are no studies to date that focus exclusively on the benefit of incorporating embodied metaphors in children's musical interactive environments.

THEORETICAL BACKROUND

As computing becomes embedded in the physical environment, understanding how metaphors may be used to support children to enact appropriate input actions and understand the relationship to resulting computational representations is important. The use of metaphor in children's interaction design may be used to help them understand how to interact with a system as well as help them understand output representations (e.g., concepts instantiated in the system). The focus of this study is on interactional metaphors rather than interface metaphors.

Metaphor

In language and thought metaphors help us understand one thing in terms of another. A metaphor is the interaction between a target domain and a source domain that involves an interaction of schemas or concepts. As such, metaphors are systematic thought structures. In the 1980s Lakoff and Johnston proposed a subclass of metaphors called *conceptual metaphors* [18]. Johnson claimed that metaphors arise unconsciously from experiential gestalts relating to the body's movements, orientation in space, and its interaction with objects [15]. He called these fundamental gestalts *embodied schemata*, also called image schemata. Conceptual metaphors extend embodied schemata to structure and organize abstract concepts.

Direct physical interaction with the world is a key component of cognitive development in childhood. Piaget began a long tradition suggesting that cognitive structuring through schemata accommodation and assimilation requires both physical and mental actions [22]. Piaget proposed that children develop abstract conceptions based in part of the extension of concrete, physical schemata. Many embodied metaphors operate at the preconscious level of awareness [11,18]. In terms of learning, psychologists have shown that children may learn something new and intuitively put it into action before they are able to verbalize it consciously [20].

Types of Embodied Metaphors

Conceptual metaphors are often (but not necessarily) extensions of embodied schemata. For example, the body's general upright position in space creates a verticality schema that results in various *spatial* (orientational) metaphors based on a vertical hierarchy [18]. When we add sticks to a pile or water to a container the level increases. Our interactions with the physical environment support the association *up* as *more* (as opposed to *down* as *more*). Orientational metaphors give an abstract concept a spatial orientation. For example, HAPPY IS UP and SAD IS DOWN. These metaphors lead to expressions in English such as “I’m feeling *up* today.” Orientational metaphors are often used to interpret music. For example, “The music *lifted* me *up*.” However, the use of orientational metaphors in understanding music is largely related to the emotional impact or content of the music, rather than individual concepts related to musical sounds (e.g., amplitude, tempo). For those interested, Hurtienne and Israel provide a good overview of some of the complementary orientational embodied (image) schemata and metaphorical extensions that may be applicable to tangible interface designs [11].

We began our investigation with the assumption that *ontological* metaphors may be more appropriate than orientational metaphors for understanding concepts related to musical sounds in a movement based system. An ontological metaphor represents an abstract concept as something concrete and physical such as an object, person, body or substance in the environment [18]. Understanding our experiences in this way allows us to treat parts of our experiences as discrete entities, or substances of a uniform kind that can be referred to, categorized, grouped, quantified and qualified. Even when things are not discretely bounded, we refer to them in this way. For example, INFLATION IS AN ENTITY allows us to reason about the abstract concept of inflation as if it was a discrete entity. Another example is MUSIC IS A SUBSTANCE. We might say “The music *flowed* into the auditorium.” Sound can be interpreted through metaphor as a discrete substance that has various physical and spatial characteristics. Alternatively, we can interpret music through the metaphor MUSIC IS BODY MOVEMENT [14]. For example, “The music *raced* to *its* conclusion.” The application of the latter musical metaphor in our interactive environment will be described in the next section. Other musical concepts such as the principle kinds of musical processes (e.g., melody, harmony, rhythm) and musical works themselves are also often understood through spatial and physical metaphor but these are not the focus of our study.

SYSTEM DESIGN AND IMPLEMENTATION

Interactive Music Systems

Recent advances in sensor systems and computer vision algorithms along with the maturation of computer generated sound systems have supported the development of interactive music systems that create music in response to body movement [7]. Systems differ in the type of sensor used and their musical capabilities. Winkler provides a good overview of movement sensing for interactive music composition [25].

With an acoustic instrument the playing interface is often integrated with the sound source. For example, with a violin the strings are part of both the control and the sound generation mechanisms. This is not so with electronic musical interfaces. The interface and control mechanism are usually completely separate from the sound source. This means that the mapping (or relationship) between control (input actions) and sound production (output responses) must be defined explicitly. Hunt *et al.* state that by altering this mapping layer and keeping the interface itself and sound source constant, the entire nature of the environment (or instrument) is changed [10]. Briefly, movement data may be mapped to musical parameters including amplitude (volume), tempo, pitch, rhythm and beat. Movement data may be selected, scaled or filtered before it is used as parameter input to compositional algorithms.

Design Goals

Our goal was to create a system that we could use as an experimental testbed to look for evidence that by leveraging embodied knowledge we can design interactive environments that support children to learn about abstract musical concepts. There are various kinds of metaphors that are used to understand different aspects of music (as previously described). However, for an interactive environment that relies on whole body movement, the ontological metaphor MUSIC IS BODY MOVEMENT is appropriate [14].

The major design goal was to create a system that related bodily movement to changes in output sound parameters (e.g., volume, tempo, pitch). The primary criterion for the system was that the interface should be distributed in a space that facilitated movement (input) and produced variable musical sound responses (output). Previous work by the authors provides evidence that children in this age range can perceive scaled differences in volume, tempo and pitch in a responsive environment [6]. A second major criterion was that the system had to support the inclusion of different mapping layers that related input movements to changes in sound output without changing the interface or the sound source. In this way, we could implement two versions of the same system for comparative purposes. One version needed to utilize the embodied metaphor MUSIC IS BODY MOVEMENT in the mapping layer between input movement and output sound changes. The other version of the system would not utilize metaphor in the mapping layer. In order to highlight the contribution of preconscious embodied knowledge rather than prior music learning or analytical ability, we had a constraint that the system should give no immediately perceivable cues to its usage. For example it should avoid a spatial layout that mimicked the layout of musical instrument (e.g., piano).

The Sound Maker Interactive Environment

Our interactive sound environment, The Sound Maker, addresses the design goals by using a camera vision system to track children’s movements in a rectilinear space. The system relates qualities of movement to changes in percussive audio output. The physical space of The Sound

Maker fills a 5.1 meter by 4.5 meter footprint and extends up to a 2.7 meter ceiling. 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).

The sensor data are mapped to four musical parameters of four sequence players. 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. The musical parameters that are controlled by body movement are *volume*, *tempo* and *pitch*. Sound for each sequencer is sent through an M-audio 410 audio interface and played on one of four Yamaha Msp5A monitor speakers placed closest to its section of the sensing area. Videos of participants learning to use The Sound Maker can be found at (www.antle.iat.sfu.ca/ EmbodiedMetaphor/SoundMaker).

Interactional Mapping Layer

The metaphor MUSIC IS BODY MOVEMENT suggests that music may be treated as human body movement. The body movement source domain helps us understand the musical sounds target domain. Implementing a metaphor in the mapping layer requires understanding relationships between source and target domains. We must identify the stable, consistent mappings between movement and sound that are often only tacitly known. To avoid subjective bias, we conducted semi-structured interviews with four experts in music and movement. We asked the experts to relate qualities and quantities of body movement, informed by Dalcroze Eurhythmics [13], with sound parameters. For example, they associated tempo with speed of movement through (or around) a space. Pitch was associated with movement up and down in a 3D space or towards and away in a 2D space.

Based on previous pilot studies we constrained inputs to qualities and quantities of movement rather than specific types of movements (e.g., jumping, stomping). We eliminated movements that were difficult to sense (e.g., moving quietly). We eliminated parameters for which there was no expert agreement or children in this age range have difficulty perceiving (e.g., timbre) [6]. We limited the parameters to three to ensure an acceptable duration for each study session. The experts also validated the polarity of the mappings. Polarity refers to the direction of gradient of change. The final mappings for the embodied metaphor based version of the system are shown in Table 1. The final mappings for the non-metaphor based version were chosen in opposition to expert opinions and are shown in Table 2.

Movement	Parameter	Mappings
Speed	Tempo	*Fast is fast* *Slow is slow*
Activity	Volume	*More is loud* *Less is quiet*
Proximity	Pitch	*Near is high* *Far is low*

Table 1. Embodied metaphor based mappings.

Movement	Parameter	Mappings
Flow	Tempo	*Smooth is fast* *Choppy is slow*
Proximity	Volume	*Far is quiet* *Near is loud*
Speed	Pitch	*Slow is high* *Fast is low*

Table 2. Non-metaphor based mappings.

METHODOLOGY

Study Design

In order to investigate the potential benefits and limitations of utilizing an embodied metaphor in interaction design we designed an experimental comparison of interactions using two Sound Maker versions: one with a mapping layer based on an embodied metaphor and one that was not. We used a between-subjects design to eliminate any learning effects. Children did the same tasks in both conditions. They were randomly assigned to each condition. For reasons of ecological validity and to promote verbalization we decided to use a collaborative, paired condition.

Participants

The study was comprised of sessions with twenty pairs of child volunteers (total 40 participants) of both genders (20 males, 20 females), aged 7 to 10 years old, recruited from an urban science centre. No previous musical experience was required. All participants used computers daily or weekly. There were no significant differences in children's preference ratings for music or physical activity between groups. Participants were randomly grouped in gender matched pairs (where possible). Ten pairs used the embodied metaphor based version of The Sound Maker and ten pairs used the non-metaphor based version.

Tasks

Recognizing, mimicking and creating simple patterns or temporal sequences with variations in volume, tempo and pitch are common activities used to teach young children music [16]. Since participants were not required to have any musical training, beginner level exercises were chosen. Paired participants were asked to work together to create sequences by moving their bodies in the space. This type of movement-based exercise is common in the Dalcroze Eurhythmics approach to music education [13].

After a free play session, the participants were given a series of three tasks in which they were asked to create specific sound sequences by varying a single parameter. For example, in the "volume" task, they were asked to make a sound sequence where the volume varied from loud to quiet and back to loud. They were given samples of how loud and how quiet the system could be. Results from two pilot studies helped us calibrate sound output scales and ensured that sensed movements created changes in sounds that children could perceive. We hypothesized that children find the embodied system easier to learn because they would utilize embodied knowledge and "naturally" move their bodies in ways that would vary each sound parameter. By giving them ample time to play with each parameter in isolation, we expected that they would come to understand, through movement, not only what each parameter was but how it could vary. The fourth task involved creating a sequence with two parameters at once. Participants were also given the opportunity to compose their own sequence, which they then physically demonstrated and explained.

For each task pairs were given up to ten minutes to practice and perfect their sequence. They were then asked to physically demonstrate and verbally explain each movement-sound sequence. We included both physical demonstration and verbal explanation because we had hypothesized that in the embodied system children might be able to more accurately demonstrate a movement-based sound sequence by relying on preconscious knowledge than be able to verbally explain how to create a sequence (which requires explicit knowledge) [20]. In order to succeed at demonstrating a sequence, a pair had to be able to understand conceptually how a sound parameter could vary as well learn how to control the system to produce that variation. In order to succeed at explaining a sequence, a pair had to understand how a sound parameter could vary, how to control the system to produce that variation and be able to describe the relationship between body movement and sound parameter. Discrepancies between demonstrated and verbal performance provide evidence for the benefit of embodied metaphor in learning to use the system but not necessarily a benefit in conceptual understanding of the musical sound parameters.

Measures

The sequence tasks facilitated the collection of several forms of data, both quantitative and qualitative. For each task, we recorded the time the participants took to practice creating sequences with a maximum of ten minutes per task. We rated the accuracy of their final physical demonstration and verbal explanation for each sequence task (correct, partially correct or incorrect). An example of a partially correct solution for demonstration of the tempo task (sequence: fast-slow-fast) is if a pair of children moved quickly and increased the tempo reliably but did not create slow tempo reliably or did not alternate fast and slow tempo variation. We noted similarities and discrepancies between how they physically performed and what they verbalized. We also took notes throughout the sessions and video taped all sessions for later analysis and validation of accuracy ratings.

Children individually completed a post session questionnaire including the Intrinsic Motivation Inventory (IMI) subscales for Enjoyment and Interest, and Perceived Competence (as described in [27]) and individual statements related to ease of learning, intuitiveness of learning and amount of concentration required to learn. Subjects rated how much they agreed with statements using a Likert style five part sad to happy face scale. Faces correspond to values one to five where a rating of five means that the child thinks that statement is very true for them. The questionnaire was read out loud to reduce the impact of differences in reading ability.

RESULTS & DISCUSSION

Quantitative

Time

Descriptive statistics for practice times in seconds are given in Table 3 for each condition. Although there is a trend for children to take longer with the non-metaphor based version on all tasks, t-tests revealed that children's practice times were not significantly different between the two conditions. The lack of significance is largely due to the large variation in practice times within both conditions as seen in the standard deviations. From our observations we suggest that personality factors may play an important role in determining how long children are willing to spend learning the system and practicing each task. A larger sample size might reduce the impact of individual differences.

	Vers*	N	Mean	Std Dev.
Task 1: Volume	Emb.	10	235	239
	Non	10	253	181
Task 2: Tempo	Emb.	10	107	158
	Non	10	195	142
Task 3 : Pitch	Emb.	10	112	86
	Non	10	123	79
Task 4: VolTempo	Emb.	10	88	129
	Non	10	179	147
Total Tasks	Emb.	10	543	540
	Non	10	749	485

Table 3. Descriptive statistics for practice time data (seconds).

*Emb. = Mapping layer utilizes an embodied metaphor; Non = mapping layer does not utilize an embodied metaphor.

Accuracy

Frequency counts of accuracy codes: correct, partially correct and incorrect, yielded expected differences in both physical demonstration and verbal explanation on all tasks except the pitch task as shown in Tables 4 through 8. Children in both groups had difficulty with the pitch task. Plausible explanations for all children's difficulty with this task are discussed below in *Discoverability*.

	Vers	Correct	Partial	In-correct
Volume Demo	Emb.	8	0	2
	Non	2	5	4
Volume Verbal	Emb.	3	3	4
	Non	2	1	7

Table 4. Volume task: Counts of accuracy codes.

	Vers	Correct	Partial	In-correct
Tempo Demo	Emb.	8	1	1
	Non	0	3	7
Tempo Verbal	Emb.	8	1	1
	Non	0	0	10

Table 5. Tempo task: Counts of accuracy codes.

	Vers	Correct	Partial	In-correct
Pitch Demo	Emb.	1	1	8
	Non	1	0	9
Pitch Verbal	Emb.	2	0	8
	Non	0	1	9

Table 6. Pitch task: Counts of accuracy codes.

	Vers	Correct	Partial	Incorrect
VolTempo Demo	Emb.	8	2	0
	Non	0	2	8
VolTempo Verbal	Emb.	3	7	0
	Non	0	0	10

Table 7. Volume-Tempo task: Counts of accuracy codes.

	Vers	Correct	Partial	Incorrect
TOTAL All tasks	Emb.	52%	19%	30%
	Non	6%	15%	79%

Table 8. All tasks: Counts of accuracy codes.

If we remove the pitch task then we find that children performed and verbalized correctly in 63% of cases with the embodied metaphor version compared to only 7% with the non-metaphor based version. Mann-Whitney tests showed significant differences between groups on demonstration accuracy across tasks except the pitch task ($U=108.0$, $p<0.0001$) and verbal explanation accuracy across tasks except the pitch task ($U=124$, $p<0.0001$). These results show a significant advantage or benefit for children using the embodied metaphor based version of The Sound Maker system.

A comparison of demonstrated versus verbal accuracy reveals that in the embodied metaphor based system and excluding the pitch task, children *correctly* performed task sequences in 80% of the cases and verbally explained their sequences in only 47% of the cases. For the non-metaphor based system and excluding the pitch task, children *incorrectly* demonstrated task sequences in 60% of the cases and verbally explained their sequences incorrectly in 90% of the cases. Analysis using a Wilcoxon W test showed significant differences between demonstration and explanation for the embodied metaphor based version group ($Z=-2.5$, $p<0.0001$). These results provide evidence that children may be able to physically perform sequences better than they can verbally explain them. A full description of inferential statistical results cannot be accommodated within the page limits of this paper.

Due to pragmatic constraints, children only had a short amount of time allocated for learning the system (50 minutes maximum). However, since all children were given the same time limit, a relative comparison is valid. Pilot studies revealed that when children have repeated use of the system, they perform better. However, this study was limited to a short and first learning session. Thus, the benefits of using an embodied metaphor in the mapping layer may be limited to guiding and constraining initial input actions.

We have no clear evidence that children came to better understand the musical concepts represented in the system. Nor do we know if children might be able to transfer this knowledge to other situations or domains [17]. The utility of this approach may be limited to a usability advantage versus a learning advantage. Despite solid quantitative results, we are cautious in our claims and further studies of longer duration are needed to explore this issue.

Experience

Descriptive statistics for experience related constructs are given in Tables 9 and 10.

	Enjoy/Interest	P. Compet.
Emb.	4.2 (.6)	3.9 (.6)
Non	4.2 (.8)	3.5 (.8)

Table 9. Mean and standard deviation for IMI subscales.

	Easy to Learn	Intuitive	Concentrate
Emb.	3.8 (.4)	3.9 (.7)	3.4 (1.4)
Non	3.2 (.8)	3.5 (.8)	3.6 (1.3)

Table 10. Mean and standard deviation for other exp. statements.

Nonparametric analysis revealed no significant differences for any constructs. However, the means show a trend in which children rated the embodied metaphor based version easier to learn, more intuitive, and requiring less concentration. Children also rated their feelings of perceived competency higher after using the embodied metaphor based version. There were no differences in enjoyment and interest. This may be an artifact of participating in an experiment at a science centre.

Qualitative Themes

Analysis of detailed observational notes and video revealed several salient themes that we use to contextualize and augment the quantitative results.

Spatial Metaphors

In an environment with few clues to use children routinely oriented to the four speakers and to the linear border of the space (indicated with taped lines on the floor). Despite instructions that indicated that the system could be controlled and understood through body movement, children looked to the spatial structure of the physical environment as they learned how to control sound parameters. For example, many children in both conditions initially thought that proximity to a speaker created a particular change in sound. In addition, children tended to explore the rectilinear space by moving in straight lines along the edges, moving diagonally across the space and attributing meaning to the corners. None of these sequences seemed to be the result of conscious or analytical decisions but rather natural inclinations. We interpret these spatially oriented behaviors to suggest that children tended to approach learning how to use the system by first relying on cues in the external physical environment in addition to (and perhaps more than) relying on the qualities and quantities of their actions in the environment. We suggest that spatial (orientational) metaphors may have precedence over bodily metaphors in the initial stages of this type of learning activity.

Discoverability

The pitch task shows the importance of creating mappings that are easily discoverable by users. In both systems children had a great deal of difficulty with the pitch task. This may have been because they had difficulty with the concept of pitch in a percussive audio environment, although previous work does not support this interpretation [6]. We observed that some pairs tended to stay either close together (often in girl-girl pairs) or far apart throughout the entire session. In the embodied metaphor based version this meant that children could not discover the effect of changing proximity on pitch. In the non-metaphor based version, the first two tasks did not reward high levels of movement speed or activity. When children began the third task (pitch) they had often settled into a pattern of slow movement since high speed and high activity levels had not been previously rewarded. This made it difficult for them to discover the mapping of speed to pitch. More study is needed but we stress the importance of discoverability of mappings in system and task design.

Natural Movements + Perceivable Feedback

We observed that many children in both conditions often enacted the qualities of movement that we had designed into the system. For example, they moved quickly (racing around the space), walked stiffly in the space, ran or jumped on the spot, moved together in a synchronized way, moved in a choppy or haphazard way. None of these actions seemed to be preplanned by the children or be the result of analytical thought so much as the result of simply moving naturally and intuitively in response to task challenges. However, learning how to control the sound parameters required that children recognized when their movements elicited the sound effect they were trying to create. It also required that children remember how they were moving to create a particular sound change and be able to duplicate it. This was more readily achieved using the embodied metaphor based version of the system. One important observation concerns the role of feedback in conjunction with natural movements. In the metaphor based version faster movement speed increased the tempo of output sounds. Here, children's initial movements were immediately rewarded with the desired changes in sound output. In the non-metaphor based version these first natural movements were not rewarded. Children often expressed some frustration or surprise and eventually resorted to other kinds of movements and actions. In some cases, they insisted that the movements they expected to work did work, even though sound feedback was clearly contrary to their claims. The importance of immediate perceptual confirmatory feedback was required to leverage embodied knowledge of the metaphorical relation between natural movements and musical sound parameters.

CONCLUSIONS

Our comparison of two mapping layers in an interactive musical sound environment allowed us to determine and reflect on fundamental differences between interacting with a system that utilized an embodied metaphor in the mapping layer and one that did not. There is a distinct advantage for children learning to use the system version based on an embodied metaphor. In addition, children's physical demonstration of knowledge outperformed their verbal abilities to explain movement-sound sequences. It is not entirely clear if the advantage extends beyond learning to use the system to benefit children's learning about the sound concepts instantiated in the system.

It is important that we investigate the claimed benefits of embodied interaction through empirical studies. Although such studies may not be conclusive, they provide valuable insight to other researchers and designers of interactive technologies for children. This study contributes empirically grounded understandings that can inform researchers and designers working in the fields of children's tangible user interfaces and interactive environments.

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