Identifying Embodied Metaphors in Children's Sound-Action Mappings

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ABSTRACT
Physical activity and manipulating physical objects can be beneficial for learning. Earlier studies [2] have shown that interaction models that rely on unconscious and embodied knowledge (based on embodied metaphors) can benefit the learning process. However, more than one embodied metaphor might be applicable. In this paper, we present the results of a user study (n=65) designed to identify embodied metaphors seven to nine year old children use when enacting abstract concepts related to musical sound. The results provide evidence that multiple different embodied metaphors can unconsciously be used to structure the understanding of these concepts. In addition, we have identified and categorized commonly used metaphors based on the children's enactments of changing sound concepts.

Categories and Subject Descriptors
H.5.2 [**Information Interfaces and Presentation (e.g., HCI)**]: User Interfaces – *haptic i/o, theory and methods, user-centered design.* K.3.0 [**Computers and Education**] : General.

General Terms
Design, Human Factors.

Keywords
Children, tangible user interfaces, tangible interaction, design research, image schemas, embodied schemas, embodied metaphor, learning, auditory interaction, music, sound enactment.

1. INTRODUCTION
Physical activity and playing with physical objects such as building blocks and jigsaw puzzles play an important role in the development of children. In the beginning of the 20th century, Montessori [17] advocated self-directed learning through the use of physical manipulatives. She observed that children were able to easily engage in play and concentrated learning with physical objects.

With the introduction of pervasive technologies, new opportunities for encouraging physical activity and using physical objects in learning have emerged. Recent studies underline the benefits of Embodied Interaction [6] and Tangible User Interfaces (TUIs) [24] for learning (e.g. [14] and [18]). Antle [1] argues that tangible systems should be very powerful in engaging children in active learning; body movement and touching and manipulating the real world are valuable for cognitive development. Zuckerman et al. [28] argue that TUIs are particularly beneficial for learning in abstract problem domains such as mathematics, as they promote sensory engagement; using multiple senses is the natural way for children to learn. O'Malley and Stanton-Fraser [18] state that manipulating physical objects encourage self-directed activity in children. Therefore, tangible interaction can be valuable for learning and new technologies offer opportunities to bringing playfulness back into learning.

Based on the idea that tangible or embodied interaction can be beneficial for learning, Antle et al. [2] developed an interactive learning environment for learning abstract concepts related to sounds. This environment, called the Sound Maker, allows children to manipulate the volume, tempo and pitch of musical sounds through body movement. Two different mappings between movement and sound-change were implemented; an embodied metaphor based mapping, and a non-metaphor based mapping. The embodied version uses a mapping based on knowledge that can automatically be applied; the mapping between input action and output sound can be understood unconsciously. In the other version, the mapping between action and output is not based on unconscious knowledge, but can be learned. A comparative study between the two versions revealed that the children using the embodied metaphor based version were more accurate in using the interface compared to children using the non-metaphor based mapping.

The Sound Maker study shows that embodied metaphors can enhance learning how to use an interface. Although the learning of the targeted concepts in musical sound (volume, tempo and pitch) was not studied, this result indicates that children would learn about these concepts more easily when using a system with embodied metaphor based mappings. In the Sound Maker prototype, one single embodied metaphor was chosen for each sound concept. However, one of the findings of the study was that children have more than one way to understand a particular sound concept. They found evidence of multiple embodied metaphors, each arising from a different experientially originating embodied schema, applicable to structure the understanding of a single sound concept. For example, changes in volume were understood in terms of high-low and active-inactive schemata.

If there are multiple ways for children to structure their understanding of a sound concept, implementing more than one embodied metaphor in an interactive learning system could potentially benefit learning. This suggests that in a system such as the Sound Maker, more than one embodied metaphor-based mapping could unconsciously be understood. Allowing children to explore multiple metaphors could make the learning process easier, support children to develop more comprehensive understandings of the learned concepts, and potentially result in understandings that are transferable to other contexts. Our research goal is to explore if and why interactive systems which incorporate multiple embodied metaphors in their interaction models support children's conceptual learning in abstract domains. This research study builds on and extends previous experiments performed with the Sound Maker prototype. We explore the benefits of incorporating multiple embodied metaphor based mappings for each sound concept. We also focus on children's actions on tangible artifacts rather than their full-body movements in order to see if previous findings can be generalized from interactive environments to tangible artifacts.

An essential step in building such a tangible learning environment as a research instrument is identifying the applicable embodied metaphors to incorporate in this learning environment. This paper reports on our investigation of different movements children use to enact changes in sound concepts, in order to identify metaphorical mappings between actions and sound changes. Though various metaphors for structuring the understanding of abstract concepts related to musical sound are suggested in literature (e.g. [10, 12, 26]), in this paper we focus on finding empirical evidence for these metaphors in children's actions. First we will look into some related work and the theoretical background of learning, embodied metaphors and music education.

2. RELATED WORK

There has been increasing interest in utilizing the benefits of tangible and embedded interaction in learning environments for children [1, 15]. One of the first examples of tangible interaction used for learning was introduced in the form of digital manipulatives presented by Resnick et al. [20]; programmable toys intended for learning about scientific concepts. Many more examples have been developed since, most of which focus on learning about abstract concepts or phenomena (also see [18]). For example 'Chromarium' [23], a tangible system that allows children to experiment with and learn about color mixing. 'Illuminating light' [25] is a tangible environment with which users can explore the behavior of light beams. Zuckerman et al. [28] present SystemBlocks, technology enhanced building blocks that can be used to simulate system dynamics, and FlowBlocks, building blocks that can used to manipulate abstract structures in order to learn mathematical principles. The value of tangible interfaces in learning in abstract domains is also recognized in frameworks for tangible learning systems presented by Marshall [15]. While many technical demonstrations and informal evaluations have been presented, there are few studies that empirically investigate how and why tangible interaction supports children's learning [2].

Some systems have also been developed specifically for sound and music interaction. Many of these systems use movement for interaction, such as BodyBeats [27], a full-body movement system which helps children in recognizing and creating patterns in sound, SMALLab [4], an interactive system designed to help students develop understanding of movement and sound, and the Music Cre8tor [22], an interactive music composition system intended for children with disabilities. The Sound Maker study [2] focuses on searching for evidence of the benefit of mappings based on embodied metaphors in children's interactive music systems. Building further on Antle et al's work, our paper focuses on understanding the benefits of using multiple embodied metaphors in learning through tangible interaction.

3. THEORETICAL BACKGROUND

3.1 Learning

Decades before digital technologies became accepted in everyday use, psychologists sought to understand the benefits of using physical objects and physical activity for learning. Bruner [5], who extensively worked together with the influential learning-psychologist Piaget, provided evidence that children often start learning how to solve problems by using physical materials. In this process, children combine three different 'modes of knowing': *action*, *image* and *symbol* [5]. For example when learning about volume by pouring water from a thin glass into a wide glass, the action of pouring water is combined with the image of the water in both glasses which eventually leads to a symbolic representation of the concept of volume. Bruner [5] states that forcing a combination of the three modes of knowing can result in a powerful representation of the world. The power of combining action, image and symbol is also underlined by experiments reported by for example Rieser et al. [21], showing that physical action can support remembering, spatial imagery and imagining different perspectives of the surroundings.

Similar influential learning theories are those of psychologists Vygotsky and Gal'perin, described in [19]. These theories emphasize that "mental acts origin in material acts" [19, p. 29]. In other words, higher psychological functions such as logical thinking and memory can only develop through physical acts such as manipulating physical objects. Similarly, Martin and Schwartz [16] describe how the learning process can be supported by a physically adaptable environment.

Marshall et al. [14] build on this while focusing on technology enhanced tangible objects for learning. Adopted from Heidegger [8], they distinguish tangibles to be used either as 'ready-to-hand' or 'present-at-hand'. Objects are *ready-to-hand* when they are used to accomplish a task; the user is focused on the task rather then on the object or tool. Objects are *present-at-hand* when the user focuses on the object itself, which allows reflecting on the activity. Marshall et al. [14] suggest that effective and productive learning should involve both ready-to-hand and present-at-hand usage of objects; this allows the child to frequently reflect on the learning activity which is needed to learn from the experience. They suggest that tangible interfaces can be very effective for learning when they allow children to alternate between these two ways of treating objects. Learning takes places when shifting between experience (e.g., actions, material acts) and reflection (e.g., symbols, mental acts).

In an interactive sound making system with multiple mappings between input action and output sound, children are encouraged to explore multiple sound objects. Multiple mappings may increase the opportunity for shifting between experience (exploring the mapping of a sound object) and reflection (reflecting on how the object is used, i.e. which metaphor is implemented). The result may be conceptual learning which is easier, more comprehensive and more readily transferable to other contexts.

3.2 Embodied Metaphors

As we have seen in the Sound Maker study, the mapping between input actions and output is a key aspect when it comes to learning. The study has indicated that children potentially learn more easily when this mapping is based on embodied metaphors. Antle [3] describes *embodied metaphors* as "the ways in which abstract concepts rely on metaphorical extensions of embodied schemata shaped by processes below the level of conscious awareness". This refers to the notion of embodied schemata, explored by Johnson [11]. Johnson defines an embodied schema as recurrent patterns or structures in (bodily) experiences. For example the IN-OUT schema is constituted by many different bodily experiences that share the pattern or structure of the IN-OUT schema, such as going out of a room or putting food into your mouth. These experiences all share the same structure or pattern and contribute to the pattern IN-OUT. Embodied schemata typically consist of a few basic components that are related in a simple structure. It is this structure of the recurrent patterns in bodily experiences that form the embodied schema.

Embodied schemata can be used to reason about abstract domains through metaphors. Metaphors figuratively extend embodied schemata; a schema is used in another situation in which the basic components are represented by entities that are no longer physical. This way, embodied schemata are metaphorically projected on several abstract domains, which allows us to reason about these domains. Embodied schemata and thus embodied experiences lay at the basis of reasoning, meaning and understanding [11]. As these schemata are embodied, Antle [3] refers to metaphors that extend embodied schemata as 'embodied metaphors'. See Figure 1 for an overview of how embodied schemata originate in bodily experiences and can be extended by embodied metaphors.

Lakoff and Johnson [13] describe different types of metaphors and their origins. They refer to *conceptual metaphors*, as "understanding one conceptual domain in terms of another". Lakoff and Johnson [13] distinguish, among others, *orientational* and *ontological* metaphors. Orientational metaphors are based on spatial orientation such as up-down, in-out, front-back, on-off, deep-shallow, near-far, etc. For example, in language we can use the metaphor HAPPY IS UP, SAD IS DOWN. Different from orientational metaphors, ontological metaphors are based on our interaction with physical objects and our own bodies. For example, abstract concepts can be understood in terms of an entity or substance; THE MIND IS A MACHINE, or MUSIC IS A SUBSTANCE.

3.3 Movement and Action in Music Education

Juntunen and Hyvönen [12] state that the body plays a major role in the process of learning and understanding abstract concepts related to musical sound. Similarly, Jensenius [10] argues that the body plays a major role in the perception of music, as music is a multimodal phenomenon. He refers to this as embodied music cognition, suggesting a link between human action and the perception of music.

When learning new abstract concepts, such as those in musical sound (e.g. volume, tempo), children unconsciously apply embodied knowledge in the form of embodied metaphors. Abstract concepts are understood in terms of other (more concrete) concepts [13]. Juntunen and Hyvönen [12] propose that body movement is metaphorically related to abstract concepts in musical sound and associated sound changes (e.g. high-low, fast-slow, soft-loud) based on children's physical experiences of movement and initial perceptions of sound. Children later learn to apply language terms to these abstract concepts. The ontological metaphor music is body movement is also used in the Sound Maker study [2]. This metaphor bridges from the physical to the

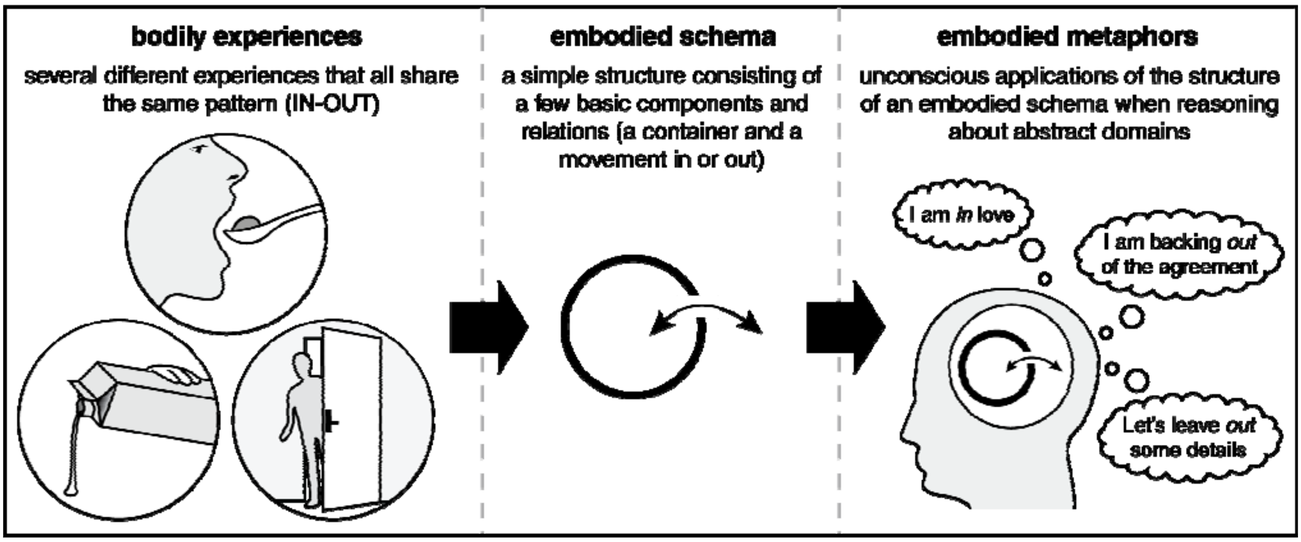

Figure 1. The relation between bodily experiences, embodied schemata and embodied metaphors.

abstract. By exploring tangible objects that instantiate different metaphors, children may seek to understand and resolve differences and in doing so, shift to a reflective mode of knowing. The experiential mode of knowing forms the basis for the reflective mode of knowing, which is essential in knowledge acquisition.

4. METHODOLOGY

4.1 Study Design

Consulting two independent music teachers, we found that the first step in music education is to become acquainted with abstract concepts in musical sound such as volume, pitch and tempo. These are generally first explained in terms of body movement. For example, the children listen to a melody played softly and to one played loudly, and are taught to react to these differences by making movements accordingly. This is needed to gain a first understanding of the abstract concepts. A next step would be to have the music react to the child's movement, as is the intention with our interactive learning system.

Our overall goal is to study how multiple metaphorical mappings between actions on physical objects and output sounds can be beneficial for learning. First, we must determine which metaphors are used by children to unconsciously structure their understanding of musical sounds. We investigated this by observing how children enacted their understandings through movement. We examined the relationships between qualities of their movements and associated sound changes to look for evidence of embodied metaphors. Our goal for the user study presented in this paper was to identify different metaphors by analyzing children's enactments. The results of this empirical work will be used to inform the design of our set of tangible sound objects for our subsequent experimental study of learning benefits, according to the commonly used design research process [9].

To search for evidence of embodied metaphors, we set up a user study in which children were asked to make movements to enact different sound changes. A second goal of the user study was to find out which musical sound concepts were recognized and understood by the children and how they described them.

4.2 Sound Concepts

Different abstract concepts in musical sound might be implemented in a learning system. Discussions with Dutch music teachers revealed that the first music classes generally start with the concepts *volume* and *tempo*, quickly followed by *pitch*. These concepts are taught roughly from the age of 4. In later lessons, the concept *timbre* is introduced. From about the age of 8, classes focus on the more difficult concepts such as *tone duration*, *rhythm*, *harmony* and *articulation*. As movement is most often used to explain the concepts, music teachers deliberately avoid using the terms *volume*, *tempo*, *pitch*, etc. Instead, the concepts are explained by their parameters (soft-loud, slow-fast, etc.).

In the user study, we studied eight different abstract concepts in musical sound. These concepts and their parameters are listed in Table 1.

Table 1. The sound concepts used in the user study, and their parameters.

Concept	Parameters
Volume	Soft – loud
Pitch	Low – high
Rhythm	Rhythmic – arrhythmic
Tempo	Slow – fast
Timbre	10 different instruments
Harmony	1 pitch – multiple pitches
Articulation	Staccato – legato
Tone duration	Short – long

4.3 Participants

Children need a basic understanding of the musical sound concepts before they can work with an interactive learning system. As children are generally ready for this next step from the age of seven, we target children of seven to nine years old. For the user study we recruited 65 children of seven to nine years old, from two different elementary schools. Among our participants, we had 35 girls and 30 boys. The participants were subdivided into 11 groups of five to seven children. Boys and girls were divided over the groups as equally as possible.

4.4 Pilot Study

A pilot study with four groups of two adults was conducted to check the exercises. This provided insight in the approximate duration of an exercise (five minutes) and the refinement of participant instructions.

4.5 Procedure

Based on the results of the pilot study, each group in the user study did three or four exercises. Each exercise was devoted to one single concept in musical sound. Since we had eight concepts (and thus eight different exercises), not all concepts were handled by each group. Most exercises were done by five groups; the exercises of *timbre* and *articulation* were done by four groups.

The exercises consisted of several parts:

1. The children listened to a short (20 second) sound sample, in which only one concept changed from one extreme to another (e.g. soft to loud tones).

2. The researcher asked the group what they have heard and asked each individual child for an answer. In case the targeted concept or its parameters were not mentioned, the sample was played again and the children were asked to explain what changed in the music.

3. The children spread across the room

4. The same sound sample was played again and the children were asked to make up a movement to enact the sound change.

5. One child was individually asked to come forward and perform his or her movement while the sample was played again, the other children moved along. This step was repeated until each child who wanted to perform in front of the group had the chance to do so.

To make sure the children would feel comfortable in these exercises, each group started with either *volume*, *tempo* or *pitch*, which are the first concepts children learn about in music education.

One of the goals of this user study was to gain input for the design of an interactive learning system, in which movement on tangible objects is coupled to changes in sound concepts. Since we eventually aim at movement on objects, it would make sense to involve objects in this user study as well. However, involving objects might also limit the creativity of the participants. Therefore, we decided to let seven groups use full body movement whereas the children in the four remaining groups were given an object to perform their movements with. The first seven groups were asked "how would you move in order to enact the sample", the latter four were asked "how would you move this object to enact the sample".

4.6 Materials

To be sure that the children were enacting the targeted concept, we created the sound samples in such a way that only the parameters of this concept changed. Each sample gradually changed from one extreme parameter to another (e.g. soft to loud). To be consistent, we used the same instrument in each sample. We chose electric piano as this instrument has the possibility of changing the parameters of most of the used sound concepts. We used a simple sequence of tones of the same pitch to make the sound change as clear as possible. Two exceptions are the samples for *harmony* and *timbre*. Since the concept *timbre* does not have extreme parameters, the sample consisted of ten different timbres, each of which four tones were played. As the pitch should not change in the sample for *harmony*, the added pitches were always the same tones, only one octave higher and one lower. The sample started with one pitch, followed by three, five and nine pitches played simultaneously.

The children in the four groups who worked with an object rather than full body movement were given a plastic, flexible ring (with a diameter of about 20 cm) to do the exercises with (see Figure 2). These objects were chosen as they have quite a lot of different interaction possibilities.

Figure 2. Flexible ring used during the object-condition of the user study.

4.7 Setting

The user study was performed at two elementary schools. In one school we used the school's gym and in the other we used an empty classroom. The exercises of nine of the groups were captures on video in order to analyze the children's movements afterwards. Two groups did not have permission to be filmed. In these two cases, the researcher made notes during the exercises. See Figure 3 for an impression of the setting of the user study.

5. RESULTS

5.1 Sound Concept Descriptions

After listening to the sound samples, the children were asked to describe what they heard. Although this question was asked in the group, each child was individually asked to respond. However, some children clearly repeated the answer from other children. These answers were not counted. Therefore, the number of answers highly differs between the different concepts. Table 2 gives an overview of the total number of answers and the number of correct answers for each concept. An answer was interpreted as correct when the concept was described correctly by using its parameters (see Table 2). When a child was successfully able to reproduce the sound change it was also seen as a correct answer as this indicates that the correct sound change has been recognized.

One important finding is that none of the children named the correct concept-name (e.g. *volume*), they only used terms for

Figure 3. Impression of the setting of the user study during the object-condition (left) and full-body movement condition (right) in the two different elementary schools.

parameter values (e.g. soft and loud). From the results shown in Table 2, we can conclude that the children had a very low understanding of the concepts *tone duration*, *harmony* and *articulation*. The understanding of the other concepts was acceptable to high.

Table 2. Results of the sound-concept descriptions as explained by the participants.

Concept	Correct answer	Number of answers	Number of correct answers
Volume	Louder / soft to loud	11	7
Tempo	Faster / slow to fast	17	11
Pitch	Higher / low to high	17	13
Tone duration	Longer / short to long	14	5
Timbre	Different sounds / instruments / musics	13	12
Rhythm	Structured to messy	17	7
Harmony	Tones were added	23	2
Articulation	Something is added after the tone	15	4

5.2 Sound-Action Mappings and Related Metaphors

After describing what they heard, the children were asked to come up with a movement to enact the sound change they heard. The children first practiced and than they could perform their enactment for the rest of the group if they wanted to. The remaining children moved along.

The videos were analyzed in order to identify the metaphors used in the children's enactments. In some cases, the children made up 'funny movements' that were clearly not related to the musical sound changes (i.e. the movements in the beginning of the sample were the same as at the end). Those cases were not counted. These occurrences may have been a result of having the children participating in groups rather than individually. However, we have also experienced that the children encourage and inspire each other while enacting sound concepts. All remaining enactments, either performed individually or in front of the group, were analyzed by one observer, via open coding. To identify the used metaphor, only the differences in movement between beginning and end of the sound sample were taken into account. This changing movement was then named as two opposite adjectives that describe the movement. For example when a child was jumping with small arm movements for soft volume and jumping with large arm movements for loud volume, only the arm movements were analyzed (as the jumping did not change over the course of the sample). The identified metaphor of this example would be a metaphor that extends the embodied schema small-big, as the movements went from small to big.

Since the metaphor MUSIC IS BODY MOVEMENT seems to be a valuable one for learning [10, 12], it would be interesting to distinguish different kinds of enactments. After clustering the found metaphors, we have distinguished enactments related to movement or location. An enactment is related to movement when the actual movement is representing the concept. For example, clapping slowly and then clapping fast or stepping gently and then stepping wildly. When the movement is only made to change from one state into another (e.g. holding hands low for low pitch and holding hands high for high pitch), the enactment is not seen as one related to movement since the characteristics of movement do not change. An enactment is related to location when the location of the object or involved body (part) is representing the concept. For example, holding the hands low and then holding the hands high or holding an object close to the chest and then holding the object away from the chest. Here the movement of the objects from one location to another links to the change in sound parameter.

Some enactments incorporated more than one metaphor. For example jumping low versus jumping high with the arms moving up and down. This enactment uses a metaphor that extends the embodied schema high-low (related to location) and one extending on small-big (related to movement).

For each enactment, the used metaphors were analyzed. Table 3 shows the used metaphors, the embodied schemata they extend and the frequency of these metaphors for each concept. As some enactments were not counted and others incorporated multiple metaphors, the numbers in Table 3 do not give the number of enactments, but the number of used metaphors. When one metaphor was used multiple times, this means that different children used the same metaphor, however, they might have used different enactments. For example, stepping slowly vs. stepping fast and clapping slowly vs. clapping fast are both interpreted to have a metaphor that extends the schema slow-fast.

An important finding is that every child used a metaphor based on slow-fast in their enactment of *tempo*. Therefore, we decided to subdivide these metaphors into slow-fast succession (when a movement was repeated slowly or fast) and slow-fast speed (when the actual speed of an ongoing movement was increased over the course of the sample).

The concepts *volume*, *pitch* and *tone duration* show a variety of metaphors, that were used by multiple different children in different sessions. For the concept *rhythm*, one clear metaphor was found (based on the schema structured – chaotic). The same goes for *timbre*, which all children enacted by making up a different movement for each timbre. For *harmony* and *articulation*, we see different metaphors, but there is not clearly one that is used most often. Concluding we can say that most concepts have more than one applicable metaphor, which were used by multiple different children in different sessions. Most of these metaphors were related to movement, whereas some were related to location.

5.3 Full body movement versus objects

7 of the 11 groups performed the exercises using full body movement while the other four groups used an object (a plastic ring). When comparing these two conditions, we found that the most frequently identified metaphors were being used in both conditions. Constraining children to use objects did not result in different metaphors.

Table 3. For the eight sound concepts: the identified embodied metaphors, the embodied schemata they extend and examples of enactments (number of identified metaphors between brackets).

Sound Concept	Metaphor Type	Embodied Schema	Example Enactment
Volume (28)	Movement (20)	Small - big (10)	Jumping low – jumping high and waving arms
		Quiet - wild (9)	Stepping softly – stepping loudly
		Slow - fast (1)	Waving slowly – waving fast
	Location (8)	Low - high (8)	Jumping low – jumping high
Tempo (17)	Movement (17)	Slow - fast succession (16)	Clapping slowly – clapping fast
		Slow - fast speed (11)	Rotating ring slowly – rotating ring fast
Pitch (26)	Movement (12)	Small - big (10)	Waving (small movements) – waving (big movements)
		Slow - fast (1)	Stepping slowly – stepping fast
		Quiet - wild (1)	Shaking head softly – shaking head wildly
	Location (14)	Low - high (14)	Holding ring low – holding ring high
Tone duration (20)	Movement (7)	Short - long (7)	Bending knees shortly – bending knees long
	Location (13)	Near - far (8)	Holding ring close to chest – holding ring away from chest
		Low - high (4)	Rotating ring low – rotating ring high
		Left - right (1)	Holding ring left – holding ring right
Timbre (14)	Movement (14)	Different movements for each timbre (14)	Imitating a different instrument for each timbre
Rhythm (10)	Movement (10)	Structured - chaotic (8)	Stepping rhythmic – stepping arrhythmic
		Slow - fast (1)	Jumping slowly – jumping fast
		Quiet - wild (1)	Shaking hands quietly - shaking hands wildly
Harmony (13)	Movement (10)	Different movements for each number of pitches (4)	1 pitch = jumping, 3 pitches = bending knees, 5 pitches = moving arms up and down, 7 pitches = moving arms from left to right
		Small - big (2)	Moving ring small distance – moving ring large distance
		One movement - multiple movements (2)	1 pitch = rotating 1 arm, 3 pitches = rotating 2 arms, 5 pitches = rotating 2 arms and 1 leg, 7 pitches = rotating 2 arms and 2 legs
		Slow - fast (1)	Waving arms slowly – waving arms fast
		Quiet - wild (1)	Shaking ring quietly – shaking ring wildly
	Location (3)	Low - high (1)	Lifting arm up low – lifting arm up high
Articulation (3)	Movement (1)	Quiet - wild (1)	Waving arms softly – waving arms wildly
	Location (2)	Low - high (1)	Holding hands low – holding hands high
		Near - far (1)	Holding hands near each other – holding hands far apart

In the full body movement condition, there were many cases in which one enactment used multiple metaphors. In the object condition however, most enactments had only one metaphor. Apparently, the objects invite for one single movement or enactment while the option to use your whole body results in multiple movements and enactments at the same time.

6. DISCUSSION

Throughout the user study described in this paper, we have learned that children use multiple different ways to structure their understanding of particular sound concepts. The movements children made up to enact sound changes were analyzed to find evidence of embodied metaphors. Furthermore, we learned which sound concepts were easy or hard to understand by children aged seven to nine.

One of the findings is that some sound concepts were better understood by the children than others. When we look at the results for the concept *articulation* for example, we see that only four out of 15 children were able to recognize this concept. Furthermore, we found that only three metaphors were found in the movements the children made. This shows that the low number of metaphors may be connected to the low understanding of the concept. On the other hand, the concept *tone duration* was also poorly recognized (five out of 14 answers were correct). This concept however showed quite a lot of sensible metaphorical enactments. For example short movements vs. long movements and near vs. far (which could represent a short object or entity versus a long one). As suggested in literature (e.g. [12]), learning and knowledge acquisition takes place when shifting between experience and reflection. Abstract concepts are first understood in terms of the experience (the metaphor MUSIC IS BODY MOVEMENT in this case) before it can be explained in words. As confirmed by our results, *tone duration* was already understood in terms of movement by several children (the bodily experience helped them structure their understanding of the concept), but not yet in words. The concept of *articulation* on the other hand, may have been too difficult for this age group; it was not understood in movement, neither in words.

During the user study, we clearly saw how children understood and explained sound concepts in terms of movement. In line with the theory (e.g. [3, 10, 12]), children understood the concepts in terms of movement before they were able to name the concepts. For example when one of the children copied the movement of another child during the *timbre*-exercise, he was so concentrated on the movement that he did not notice all individual timbres. Afterward he came to one of the researchers and said “this was a different sample, I did not hear this sound” and he made a movement he had made up to enact one of timbres. This shows how movement may be an essential part of the learning and understanding process of such abstract concepts.

Another interesting finding relates to the concept *timbre*. Although almost all children (12 out of 13) were able to recognize this concept, no clear metaphorical sound-action mapping was found. *Timbre* might not be a typical concept that is understood in terms of a metaphor. As *timbre* is usually not described in terms of two opposite adjectives (as opposed to many other sound concepts), it might be difficult to enact it as such. This is also in line with the results of an experiment presented by Droumeva et al. [7], showing that auditory feedback in interactive systems is less easily perceived by children when it is based on *timbre* compared to for example *pitch*.

In the Sound Maker study, the metaphor MUSIC IS BODY MOVEMENT is used in the mapping between action and sound change. In literature, this is also regarded as a valuable metaphor for music education [10, 12]. We found that some metaphors we identified were related to location rather than movement. Especially for pitch, there is a clear location related metaphor applicable (based on the embodied schema low-high), which indicates that the metaphor MUSIC IS BODY MOVEMENT might not be the most suitable metaphor for all concepts. This turned out to be in line with [2] and with theory; specifically for pitch Zbikowski [26] uses the metaphor PITCH RELATIONSHIPS ARE RELATIONSHIPS IN VERTICAL SPACE. As this metaphor originates in the embodied schema high-low or up-down, this metaphor may also be regarded an embodied metaphor.

In the user study presented in this paper, a part of the participants used full-body movement whereas the rest worked with an object. When comparing these two conditions, we found that constraining children to use objects did not change the embodied schemata or related metaphors used to structure their understandings of musical sound concepts. This provides support for the generalizability of the use of embodied metaphor in all interactive systems that use movement as system input.

As explained before, the metaphors identified in this paper are intended to inform the design of a tangible learning system targeting musical sound concepts. In order to study the learning benefits of multiple embodied metaphors, this learning environment requires multiple mappings for each sound concept. As we have seen in the user study, the children in the full-body movement condition often used more than one metaphor in their enactment, whereas mostly single metaphors were seen in the object condition. Physical objects can clearly afford the targeted metaphor, which is more difficult in full-body movement interfaces. Therefore, offering children different tangible artifacts, each designed for a different metaphor, allows for studying the effects of metaphors on learning.

7. CONCLUSIONS

In this paper, we describe a user study in which children enacted changes in musical sound concepts through movement. From these movements, we have been able to uncover embodied metaphors that children use to structure their understanding of these concepts. This provides empirical evidence that children enact movements that reveal embodied metaphors in their understanding of sound concepts, which confirms that the theory of embodied metaphors can benefit the domain of sound and music education and contributes to our understanding of the benefits of embodied interaction for learning. This paper adds to existing work by describing a process which can be used to identify embodied metaphors grounded in movement and spatial location target domains in order to inform the design of interactive systems. Through this process, we explicitly identified embodied metaphors that are commonly used in sound-action mappings in order to inform the design process. This work has provided us with a more complete understanding of the ways children use metaphors to structure their understanding of sound concepts, which could benefit the eventual learning process.

The results of the user study confirm that children enact multiple different embodied metaphors in their understanding of particular abstract concepts related to musical sound. This provides support for the strategy of including multiple mappings in an interactive learning environment in order to leverage unconscious and embodied knowledge. In addition, the results of the user study show that, as opposed to full-body movement, movement with objects invites for one single enactment per object. This supports the use of tangible interaction in the design of interactive learning environments with multiple mappings.

It is important that we investigate the potential benefits of embodied metaphor through empirical studies. Such studies provide valuable insight into how and why embodied and tangible interaction may be beneficial. This study contributes a process for identifying embodied metaphors and presents empirically grounded results that can inform researchers and designers working in the fields of children's tangible user interfaces and interactive environments.

8. FUTURE WORK

The results of this user study will be used to inform the design and development of an interactive system using tangible interaction that supports children to learn about abstract concepts related to musical sound. This system will be used to study how multiple mappings between actions on physical objects and output sounds can be beneficial for learning. This research builds on, validates and extends previous research described in [2, 3] by incorporating multiple (versus single) embodied metaphors in the interaction models for a set of tangible artifacts (versus full-body movement in an interactive environment).

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