

MoSo Tangibles: Evaluating Embodied Learning

Saskia Bakker¹, Elise van den Hoven¹, and Alissa N. Antle²

¹Department of Industrial Design
Eindhoven University of Technology
Eindhoven, the Netherlands
{s.bakker, e.v.d.hoven}@tue.nl

²School of Interactive Arts and Technology
Simon Fraser University
Surrey, B.C., Canada
aantle@sfu.ca

ABSTRACT

Using tangible interaction in interactive educational systems can benefit learning. This can be supported by relying on experientially originating schemata in the interaction design of learning systems. This paper presents the design and evaluation of MoSo Tangibles, a set of interactive, physical artifacts with which children manipulate the pitch, volume and tempo of ongoing tones, in order to structure their understanding of these abstract sound concepts in terms of multiple different concrete body-based concepts. The results indicate that MoSo provided children with a physical handle to reason about the targeted abstract concepts.

Author Keywords

Tangible and embodied interaction, design research, embodied schemata, metaphors, learning systems, children.

ACM Classification Keywords

H.5.2 Information Interfaces and Presentation (e.g., HCI): User Interfaces – *evaluation/methodology, interaction styles, user-centered design*. K.3.0 Computers and Education: General.

General Terms

Design

INTRODUCTION

For ages, physical activity and manipulating physical objects have played an important role in learning and development. Building on this, many studies in the area of tangible and embodied interaction [8, 26] have focused on developing physical interactive learning systems [10, 22]. Such studies discuss several potential benefits of these interaction styles for learning, such as promoting self-reflection [28], engagement [2] and self-directed activity [18].

In previous work on interactive learning systems [4, 5], we have developed and studied mappings between input actions and output changes that are based on so-called

embodied metaphors, unconscious knowledge originating in body movement that can be applied automatically. A study with the interactive Sound Maker environment [3], designed to support children when learning about abstract sound concepts such as pitch and volume, indicated that systems with embodied metaphor based interaction models may support children in structuring their understanding of these abstract concepts. Furthermore, the study revealed that children may rely on multiple different embodied metaphors in their understanding of abstract (sound) concepts. This was verified in a further study, which indicated that seven to nine year old children can use different embodied metaphors in their reasoning about abstract sound concepts [5]. For example, they may understand soft and loud volume in terms of slow and fast movements, but also in terms of small and big movement.

Knowing that children can structure their understanding of abstract sound concepts in different ways, implementing more than one embodied metaphor in an interactive system could potentially benefit learning. This would enable children to explore multiple movements to reason about one concept, which could support developing a more comprehensive understanding of the learned concepts and potentially result in understandings that are more easily transferable to other domains. This also corresponds to a frequently used approach of using multiple representations when teaching complex scientific concepts [25]. The research presented in this paper aims at exploring if and why interactive systems that incorporate multiple embodied metaphors in their interaction models can support children's conceptual learning in abstract domains.

We present a user study in which 39 seven to nine year old children used a specifically designed tangible learning system, named Moving Sounds (MoSo) Tangibles that implements three different embodied metaphor based interaction models for learning about single sound concepts. The aim of this study was to compare learning effects of a system with multiple mappings, to learning effects of a similar system with one mapping. First we will look into the theoretical background and related work.

THEORETICAL BACKGROUND

Embodied Metaphors

In previous work, we have seen that learning of abstract concepts may be supported by interactive systems that rely on so-called embodied metaphors. This is grounded in

Permission to make digital or hard copies of all or part of this work for personal or classroom use is granted without fee provided that copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. To copy otherwise, or republish, to post on servers or to redistribute to lists, requires prior specific permission and/or a fee.

TEI'11, January 22–26, 2011, Funchal, Portugal.

Copyright 2011 ACM 978-1-4503-0478-8/11/01...\$10.00.

theory suggesting that recurrent patterns of bodily experiences form the foundation of abstract thinking and reasoning [20]. These recurrent patterns emerging from bodily experiences are commonly called image schemata or embodied schemata [15]. For example, the IN-OUT schema is formed as a result of several experiences related to in and out: we put food into our mouth, go out of a room and pour milk out of a bottle. Numerous experiences we have from the day we are born contribute to the schema IN-OUT, which consists of two basic components: a container and a movement in or out of it (see Figure 1).

People apply these embodied schemata unconsciously to reason about abstract concepts. For example, when we say “I am backing out of the agreement”, we view the concept ‘agreement’ as a container and ourselves as an entity that is in or out of this container. In other words, we understand one concept (the agreement) in terms of another concept (container). This form of projecting the structure of an experientially originating schema onto a conceptual domain is what is meant by metaphor [17]. When schemata find their origin in bodily experiences, we call them *embodied schemata* and their metaphorical extensions *embodied metaphors*.

Learning Theories

Manipulating physical objects plays an important role in children’s education. Think of an abacus and simple building blocks that have helped us understand abstract concepts related to physics and mathematics. Several psychologists have studied benefits of such approaches for cognitive development. Bruner [7] has for example shown that physical objects play a major role in bridging the abstract and the concrete. Vygotsky and Galperin [19] even state that higher psychological functions such as logical thinking can only be developed through physical acts such as manipulating physical artifacts. For example when playing with an abacus, a child will first start sliding the beads, after which he or she will see the beads being regrouped. This combination of physical experience (sliding) and reflection (noticing the regrouped beads) lays at the basis of learning and knowledge acquisition (gaining a symbolic understanding of the concept ‘addition’) [1].

Although many studies are known on the manipulation of physical objects in mathematics education, body movement also plays a major role in learning about abstract concepts related to musical sound [14, 16], which is the area for which our MoSo Tangibles system is designed. Jensenius [14] uses the term ‘embodied music cognition’ when stating that children unconsciously apply embodied metaphors when learning new abstract musical concepts such as pitch or volume. For example, children can understand the concept pitch (low versus high) in terms of concrete, movement related concepts (for example up versus down or slow versus fast). Music teachers use various such movement related metaphors when teaching abstract sound concepts [14, 16], for example by encouraging children to move slowly when music with low pitch is played, and fast when high music is heard.

RELATED WORK

Several examples of tangible interaction for learning and education are known, most of which focus on learning in abstract problem domains. Zuckerman et al. [28] discuss SystemBlocks and FlowBlocks as examples of ‘Montessori-inspired Manipulatives’; technology enhanced building blocks designed for learning about abstract mathematical principles. Smith [24] presents a tangible programming system for young children; simple cubes that can be arranged to construct a basic program directing a toy car. Girouard et al. [10] present SmartBlocks, a tangible interface with which children can explore the volume and surface area of 3D objects. Tangible and embodied interaction is also applied in the area of music education. For example “Marble Track Audio Manipulator” [6], with which children can create musical compositions, and BodyBeats [27], a whole body interactive system that supports children in recognizing patterns in sound.

Furthermore, the approach of designing interactive systems that rely on metaphorical mappings between input action and output change is promoted by several others. Hurtienne et al. [13] present a useful database of image schemata usable in interaction design. Fels et al. [9] use metaphor in their interface design for musical expression. The earlier mentioned Sound Maker interactive environment [3] used

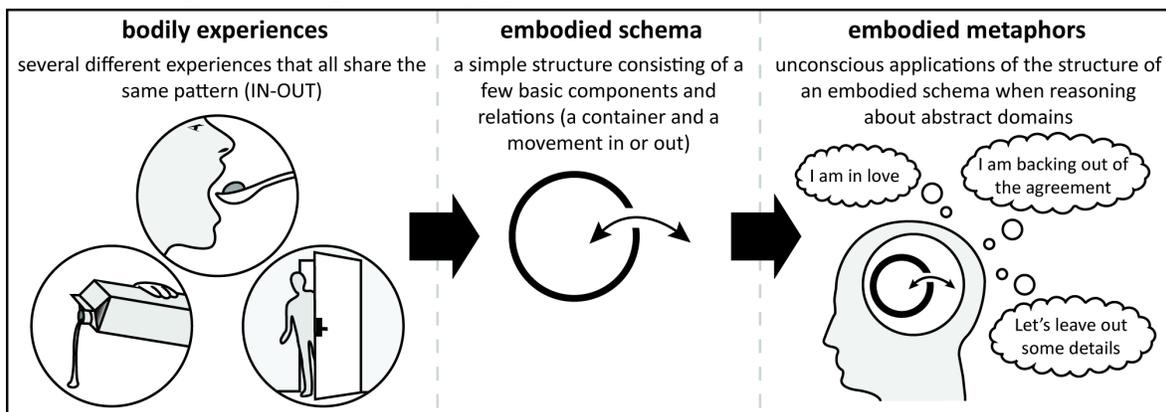


Figure 1. The relation between bodily experiences, embodied schemata and embodied metaphors.

embodied metaphor based interaction models to support children's learning of abstract sound concepts.

MOSO TANGIBLES DESIGN

The aim of the research described in this paper is to study learning effects of interactive tangible systems that rely on embodied metaphor based interaction models. Since our previous research [5] has shown that children may have multiple ways to structure their understanding of single abstract sound concepts, we expect that implementing multiple different mappings (each based on a bodily originating schema) can benefit the child's understanding of the targeted abstract concept. In order to evaluate this, we have developed an interactive learning environment, called Moving Sounds (MoSo) Tangibles, which implements multiple mappings to learn about single abstract concepts.

Building on previous work [3], MoSo focuses on teaching the abstract sound concepts pitch, volume and tempo. In consultation with two music teachers, we found that becoming acquainted with these concepts is the first step in music education. From the age of five, children are explained about the concepts in terms of body movement. For example, the teacher plays a simple melody slowly and children are taught to react to this with slow movements. After that, the melody is played fast and children make fast movements. This way children can start understanding the abstract concept tempo in terms of familiar movement related concepts (slow and fast). Such exercises provide them with a preliminary understanding of pitch, volume and tempo. A next step in this understanding would be to have the music react to the child's movement. This would enable free exploration of the concepts and will add to the child's ability to reason about changes in the concept parameters. According to the music teachers, children are ready for this step from the age of seven, when they have a preliminary understanding of the involved concepts. Our target group therefore consists of seven to nine year old children.

Moving Sounds (MoSo) Tangibles enables children to manipulate the pitch, volume or tempo of ongoing piano tones, by moving dedicated tangible artifacts. Each sound concept can be manipulated in three different ways (each based on a movement related schema), through three different tangible artifacts. This supports children in structuring their understanding of each concept in terms of three different embodied metaphors. We chose to use tangible interaction in this design rather than whole body interaction (which was implemented in our Sound Maker environment [3]), as this allows a clear distinction between the different mappings, each in a separate tangible artifact.

MoSo was developed through an extensive iterative design process, described in [4]. In the first iteration, the embodied metaphors that underlie how children reason about the selected abstract sound concepts were identified through enactment studies with 65 children [5]. As a result of this study, we found for example that children structured their

understandings of the concept volume by making movements related to the embodied schemata SMALL-BIG, QUIET-WILD, SLOW-FAST and LOW-HIGH. In the second iteration [4], low-fidelity prototypes designed based on the elicited embodied metaphors were evaluated with 50 children, which enabled assessing the implementation of embodied metaphors in terms of affordances.

Following from the above described iterations, we selected the embodied schemata NEAR-FAR, LOW-HIGH and SLOW-FAST to base our artifacts for manipulating pitch on. For volume, we selected QUIET-WILD, SMALL-BIG and SLOW-FAST. When enacting changing tempo, we found that all children based their movements on the schema SLOW-FAST, likely because the dynamics of action and sound are isomorphic (fast movements is directly related to fast sound). To enable children to structure their understanding of tempo in different ways, we subdivided the schema SLOW-FAST in SLOW-FAST succession (when a movement is *repeated* slowly and fast, e.g. clapping slowly or fast) and SLOW-FAST speed (when the *actual speed* of the movement differs, e.g. rotating your arms slowly and fast).

Resulting from the second design iteration, we designed three different tangible artifacts for each individual sound concept, based on the above mentioned schemata. These designs were developed into working prototypes of MoSo Tangibles. Figure 2 gives an overview of MoSo Tangibles, the embodied schemata they are based on, the mappings we used and the names we will use in this paper to refer to each separate artifact. As seen in Figure 2, the 'rotator' is used for all three concepts. Earlier iterations [4] revealed that a rotating movement seemed the clearest and most sensible way to map the schema SLOW-FAST speed to sound changes. Since this schema was applicable to all three concepts we decided to use the same artifact three times.

Each MoSo Tangible contains basic sensor technology to measure the intended movements. The sensor data is wirelessly transmitted to a computer which runs a dedicated program that determines the appropriate pitch, volume or tempo and produces piano tones accordingly.

USER EVALUATION

Based on previous work [5], we have found that children have multiple ways of structuring their understanding of abstract (sound) concepts. In line with approaches to teaching complex scientific concepts [25], we expect that the process of learning about abstract sound concepts may benefit from interactive systems that enable children to explore the targeted concepts through multiple different (embodied metaphor based) interactions. To evaluate this, we have set up a user study with MoSo Tangibles.

Participants and Conditions

For this user study, we recruited 39 participants (age seven to nine, 25 girls and 14 boys). Each participant interacted with MoSo in an individual session of about 20 minutes.

Pitch			
	<p>Interaction: pointing upward and downward Embodied schema: LOW-HIGH Mapping: low = low pitch high = high pitch</p>	<p>Interaction: pulling handles to different distances from each other Embodied schema: NEAR-FAR Mapping: near = low pitch far = high pitch</p>	<p>Interaction: rotating Embodied schema: SLOW-FAST Mapping: slow movement = low pitch fast movement = high pitch</p>
Volume			
	<p>Interaction: waving ribbon around Embodied schema: SMALL-BIG Mapping: small movement = soft volume big movement = loud volume</p>	<p>Interaction: pressing/squeezing wooden parts together Embodied schema: QUIET-WILD Mapping: quiet movement = soft volume wild movement = loud volume</p>	<p>Interaction: rotating Embodied schema: SLOW-FAST Mapping: slow movement = soft volume fast movement = loud volume</p>
Tempo			
	<p>Interaction: shaking up and down Embodied schema: SLOW-FAST (succession) Mapping: slow movement = slow tempo fast movement = fast tempo</p>	<p>Interaction: moving in and out Embodied schema: SLOW-FAST (succession) Mapping: slow movement = slow tempo fast movement = fast tempo</p>	<p>Interaction: rotating Embodied schema: SLOW-FAST (speed) Mapping: slow movement = slow tempo fast movement = fast tempo</p>

Figure 2. The tangible artifacts designed for manipulating pitch (top three), volume (middle three) and tempo (bottom three), and a description of the intended interactions, implemented embodied schemata and mappings.

These sessions were divided into three parts of equal length: one to learn about pitch, one to learn about volume and one to learn about tempo. The participants were divided over two conditions. Children in the *one-artifact-condition* learned about the sound concepts with one MoSo Tangible per concept: either stick, puller or rotator for pitch, either waver, squeezer or rotator for volume and either shaker, accordion or rotator for tempo. To keep it clear, no children in the *one-artifact-condition* were given the rotator to manipulate more than one concept. The children in the *three-artifact-condition* were given all three artifacts to explore each concept; puller, stick *and* rotator for pitch, etc.

The MoSo Tangibles system consists of three interactive artifacts for each of the concepts pitch, volume and tempo. All these tangibles implement an experimentally elicited embodied metaphor in their interaction models. As none of these metaphors can be considered stronger or weaker than others, we equally divided the artifacts over the *one-*

artifact-condition sessions (for example one third of the children used the puller for pitch, one third used the stick and one third used the rotator). As the *one-artifact-condition* can therefore be regarded as three separate conditions, we assigned 27 children to the *one-artifact-condition* and 12 to the *three-artifact-condition*.

Pilot study

The procedure of this user study was verified in a pilot study with eight children of seven to eight years old. This led to a refinement in the instructions given to the children.

Procedure

In the individual sessions held in this user study, each child interacted with MoSo in three separate parts; one for pitch, one for volume and one for tempo. Each of these parts consisted of an exploration phase and three reproduction tasks. In the exploration phase, each child had three minutes to explore the working of one (*one-artifact-condition*) or

three (*three-artifact-condition*) MoSo Tangibles to manipulate either pitch, volume or tempo. The children were not given any explanation about how to move the artifacts or which musical parameter to manipulate. The children were only told that the music would change as they moved the artifact(s).

After having explored the working of one (*one-artifact-condition*) or three (*three-artifact-condition*) tangibles, the child used (one of) the explored artifact(s) to perform three reproduction tasks with. In these tasks, which each lasted one minute, an example sound was played (e.g. low to high pitch) and the child was asked to reproduce this sound with the artifact. The children in the *one-artifact-condition* used the same tangible for all three tasks, while the children in the *three-artifact-condition* were given a different tangible for each task. After performing the reproduction tasks, the children in the *three-artifact-condition* were shortly asked which of the three artifacts they thought fit the sound change best. This was repeated for all three sound concepts (pitch, volume and tempo).

The order in which the children learned about pitch, volume and tempo was counterbalanced over the different individual sessions. This also holds for the order in which the children explored the different MoSo Tangibles in the *three-artifact-condition*. The individual sessions were performed in a room in which only one child and the experimenter were present. These sessions were captured on video to enable video analysis.

Formally Assessing Learning

In recent years, many studies on tangible interaction for learning have been published (e.g. [12, 28]). Evaluations of such systems often focus on user experience. However, hardly any studies aim at finding empirical evidence for an actual learning benefit of tangible systems (an exception is [21]). Although user experience may influence learning, we were interested in finding empirically grounded evidence for a learning effect of MoSo. Our user study therefore partly consisted of a quantitative analysis to evaluate if children in the *three-artifact-condition* would gain a better understanding of the sound concepts as a result of the exercises with MoSo, compared to the *one-artifact-condition*. Consultation with two music teachers revealed that no tool to measure understanding of pitch, volume or tempo exists. Therefore, the music teachers worked with us to develop a ‘sound knowledge test’ that assesses the children’s understanding of these concepts. As the children may not yet be able to verbalize their understanding of sound concepts, the test consisted of multiple choice questions. For each question, an example sound was played in which one sound concept changed (e.g. low to high pitch), followed by three alternative sounds (e.g. one in which pitch changed, one in which volume changed and one in which tempo changed). The children were asked which alternative sounded most like the example. This test was iterated once by pilot testing it with 50 children.

Each child took the sound knowledge test three times: once before the experiment, once directly after interacting with MoSo Tangibles and once six weeks after the study. To assess the reliability of the knowledge test, we calculated the correlation between the results for each of the three times the test was administered. The results did not confirm the test’s reliability ($n = 39$; $\rho = 0.2198$; $p > 0.10$). Although the correlation between the results of the three tests is not an ideal measure for assessing the test’s reliability, it is the only measure we have available. We did not administer the test more often or with other children. Therefore we cannot use the knowledge test results to draw conclusions regarding learning benefits of tangible systems. As a result, we have used video analysis results of the study to assess learning effects. Nonetheless, we feel that it is important to mention our attempt, as it may inform other studies in the field of tangible and embodied interaction for learning.

RESULTS

Video Analysis

To better understand the learning effects experienced by the children in the two conditions, we analyzed the videos of the user study. In the analysis, we identified and recorded the expressions children used when explaining about pitch, volume and tempo, as well as the expressions participants made when listening to sound samples. Though unsolicited, each child made such expressions. These expressions can indicate the children’s understanding of the abstract concepts. In total, we captured 457 expressions (295 from the 27 children in the *one-artifact-condition* and 162 from the 12 children in the *three-artifact-condition*).

The expressions we found were either verbal (e.g. imitating sounds or using words such as slow and fast) or non-verbal (movements or gestures) and were categorized via open coding. As each expression related to one of the MoSo Tangibles, we were able to count the number of expressions in each category, related to each artifact. See Figure 3 for an overview of the relative number of expressions made about the concepts pitch, volume and tempo.

As depicted in Figure 3, in approximately 80% to 90% of the cases, children used words (verbal expressions) to explain about the concepts pitch, volume and tempo. 10% to 20% of the explanations were provided in movements. These expressions all related to artifacts the children had just used (e.g. when a child had just used the shaker to manipulate tempo, he would say “the music went like this” and move his hands as if he was moving the shaker).

The children in both conditions mainly used words related to soft and loud to explain about volume. For tempo, the children mainly used words related to slow and fast, however, we also saw quite a number of verbal expressions related to soft and loud. This is due to the fact that the user study was performed in Dutch. Different from English, the Dutch words for soft and loud (*zacht* and *hard*) can also be used to indicate speed. Compared to tempo and volume, the

children less frequently used the ‘correct’ words to explain pitch (low and high). Instead, they resorted to other expressions such as the words slow and fast, or movements related to the artifacts they had just used.

When we compare the *one-artifact-condition* to the *three-artifact-condition*, we do not see clear differences for any of the concepts pitch, volume or tempo.

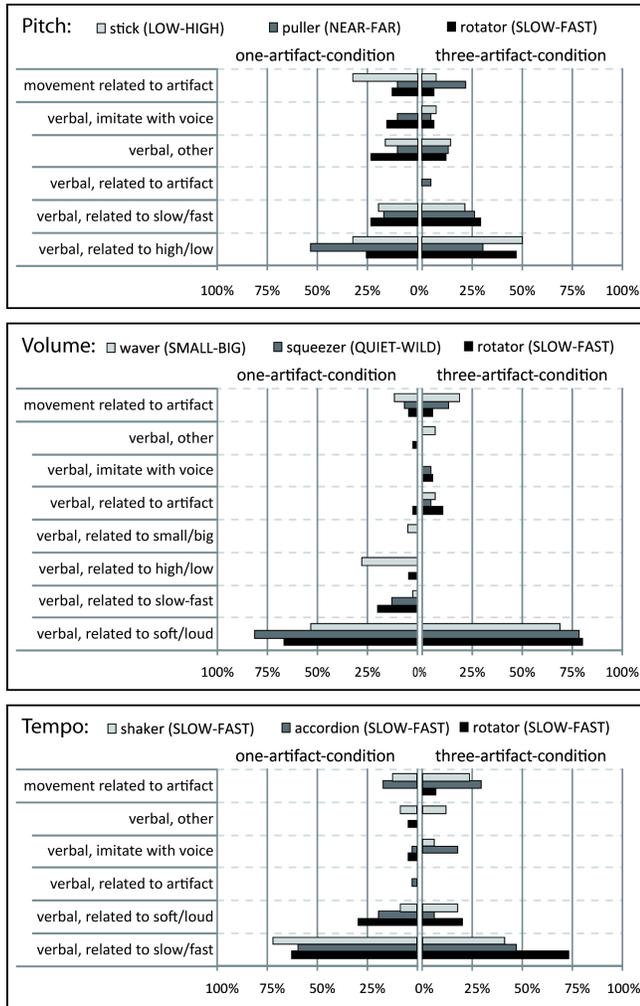


Figure 3. For pitch (top), volume (middle) and tempo (bottom), in the *one-artifact-condition* and the *three-artifact-condition*: the relative number of expressions found in each category, for each tangible (e.g. for pitch, in the *one-artifact-condition*, approximately 32% of all expressions related to the stick were non-verbal expressions).

From the video, we also analyzed the extent to which children were able to successfully reproduce sound samples using the MoSo Tangibles. As a result, we found that all children in both conditions were able to correctly reproduce the sounds within the given one minute for each task. Approximately 75% of the reproduction tasks were performed without any interference of the researcher, while the researcher needed to provide some additional explanation in approximately 25% of all reproductions.

However, this was limited to giving hints such as “do you remember what you heard in the example?” or “how did you previously move the artifact?”. The children were never explained how to move the artifacts to reach sound changes. The number of times such hints were needed did not differ significantly between the two conditions.

Interviews

In the *three-artifact condition*, each child interacted with three different MoSo Tangibles to learn about one single sound concept. After manipulating each sound concept, the children in this condition were asked which of three artifacts they thought fit the sound change best (i.e. which interaction model made most sense to them). The results of these interviews show an approximately equal division of the children’s choices over the different artifacts. For example for pitch, three children chose the rotator, four children selected the puller and five children thought that the stick fit the pitch changes best.

DISCUSSION

The study described in this paper evaluated the learning experiences of children when interacting with MoSo Tangibles, which aims at learning about the abstract sound concepts pitch, volume and tempo. In this section we will discuss insights we gained through this research.

Using Multiple Metaphorical Mappings

The aim of the study presented in this paper was to evaluate whether interactive learning systems that enable children to reason about abstract concepts through multiple different embodied metaphors would lead to different learning experiences compared to systems that implement only one metaphor. When comparing the video analysis results between the *one-artifact-condition* and the *three-artifact-condition* however, we see no clear differences between the two. We have therefore not found evidence to prove that learning can be supported by enabling children to structure their understanding of abstract concept through multiple different movements. However, this also shows that being subjected to multiple different interactions did not confuse the children or hinder their learning experiences.

The fact that no difference was found between the two conditions may be a result of the short time of approximately six minutes that each child had to learn about pitch, volume and tempo with MoSo. It may have been unrealistic to expect strong differences in learning results in such a short period. Further research with longer term experiments would therefore be needed to validate the approach of implementing multiple metaphorical interactions in tangible learning environments for children.

Embodied Metaphor Based Tangibles and Learning

As discussed above, no clear advantage was found for using *multiple* different metaphorical mappings over a *single* mapping. In this section, we discuss learning benefits of

embodied metaphor based mappings in MoSo, without comparing the two conditions. A video analysis of the children's interactions with MoSo was conducted to assess their learning experiences. As a result, we saw that the children mostly used verbal expressions to explain about pitch, volume and tempo, though movements or gestures were used in approximately 10% to 20% of the cases.

When looking at the verbal expressions children used to explain about the sound concepts, we see that for volume and tempo, children used the 'right' words in approximately 60% of all cases. For pitch, this percentage was lower, approximately 35%. Clearly, not all children were able to use the correct words to explain about the abstract concepts. In other words, not all children could verbally express their conceptual understanding of pitch, volume or tempo. When we look at the reproduction tasks however, we see that all participants were able to use the MoSo Tangibles to reproduce changes in pitch, volume and tempo. This indicates that the children could perceptually recognize the changes in sound concepts and use movement to reproduce them, regardless of the fact that some of these children were not able to verbalize their understanding of these concepts. This indicates that those children were able to reason about pitch, volume and tempo, be it using movement rather than words. This implies that when children do not yet have a conceptual understanding of a concept which they can verbalize, embodied metaphor based learning systems can serve as a handle to reason about such concepts.

Despite the small percentage of non-verbal expressions, we looked at these in more detail, as being able to gesture or move as a demonstration of knowledge is often seen as a good precursor to conceptual understanding [11]. Furthermore, gesturing can support children's verbalization, which is also referred to as 'embodied thinking' [23]. Although children may use different kinds of movements to structure their understanding of sound concepts (also see [5]), all movements that we have seen in our study related to artifacts that the children had just interacted with. This is partly expected as the participants had just been 'taught' to use that particular movement. However, the fact that no single other movement was found, even not in the *three-artifact-condition* where children explored multiple different movements, may indicate that tangible interactions based on embodied metaphors could guide children in using particular movements to structure their understanding of abstract (sound) concepts.

MoSo Tangibles Design

The user study presented in this paper used the specifically designed MoSo Tangibles learning system. The MoSo Tangibles each implemented a different embodied schema to map input movement to output sound change. As discussed before, all 39 participants in our user evaluation were able to successfully interact with MoSo tangibles, regardless of which of the artifacts they used. This shows that the design of the interactive artifacts was not stronger

or weaker for particular tangible artifacts compared to others. This is further reflected in the results of the interviews taken in the *three-artifact-condition*, demonstrating that the children's preferences were equally divided over all the designs.

The result that our participants were able to find out how to interact with MoSo within the set timeframe of three minutes of exploration is also interesting when compared to our previous work. In our previously performed Sound Maker study [3], in which children manipulated pitch, volume and tempo of sound through whole body interaction, we saw that some children were not able to discover the mapping of the system within the set timeframe, even though these mappings were also designed according to embodied metaphors. Tangible interaction can offer clearer affordances than whole body interactive environments, which has evidently enabled the participants to quickly find out how to operate the tangibles. This shows that tangible interaction is a suitable interaction style for embodied metaphor based systems.

Language and Cultural Differences

Embodied metaphor theory finds its basis in cognitive linguistics (see [15, 17]). Although it is important to understand that it is not just a linguistic mechanism as metaphorical thinking is fundamental to human thought, the link to language is important. We experienced this in our user study. We performed our study in the Netherlands, and the researchers communicated with the participants in Dutch. The Dutch words for soft and loud can also be used referring to slow and fast speed. As a result, many children used 'soft' and 'loud' to explain about tempo, or 'slow' and 'fast' to explain about volume. Furthermore, as a result of an iterative design process [4], we implemented the schema SLOW-FAST in one of our mappings for volume in MoSo Tangibles. As these words are differently used in English, one may question if iterations done with children whose first language is English would have lead to the same results. We extracted embodied metaphors from movements [5], which we believe to be cross cultural. However, evaluating this may indicate the potential influence of language on the identified embodied metaphors, and thus the way we reason about abstract concepts.

CONCLUSIONS

In this paper, we have presented the design and evaluation of MoSo tangibles, an interactive learning system that enables children of seven to nine years old to learn about the abstract sound concepts pitch, volume and tempo, through multiple different embodied metaphor based interactions. A user evaluation of this interactive system among 39 children in the target age group has shown that all children were able to successfully interact with the tangibles when reproducing examples sounds. As not all children were able to verbally express their understanding of the targeted abstract concepts, this indicates that

embodied metaphor based learning systems can serve as a physical handle to reason about such concepts.

Our study contributes to the growing body of empirical work exploring how conceptual metaphor theory can be used to inform the design of abstract domain applications on tangible, embodied and embedded platforms.

REFERENCES

1. Ackermann, E.K. Perspective-Taking and object Construction: Two Keys to Learning. In *Constructionism in Practice: Designing, Thinking, and Learning in a Digital World*. Lawrence Erlbaum Associates, Mahwah, NJ, USA, 1996, 25-37.
2. Antle, A.N. The CTI framework: informing the design of tangible systems for children. In *Proc. TEI 2007*, ACM Press (2007), 195-202.
3. Antle, A.N., Droumeva, M., and Corness, G. Playing with the sound maker: do embodied metaphors help children learn? In *Proc. IDC 2008*, ACM Press (2008), 178-185.
4. Bakker, S., Antle, A.N., and Hoven, E. van den. Embodied Metaphors in Tangible Interaction Design. *Personal and Ubiquitous Computing, special issue on Tangibles and Children*. In press.
5. Bakker, S., Antle, A.N., and Hoven, E. van den. Identifying embodied metaphors in children's sound-action mappings. In *Proc. IDC 2009*, ACM Press (2009), 140-149.
6. Bean, A., Siddiqi, S., Chowdhury, A., Whited, B., Shaer, O. and Jacob, R.J.K. Marble track audio manipulator (MTAM): a tangible user interface for audio composition. In *Proc. TEI 2008*, ACM Press (2008), 27-30.
7. Bruner, J.S. *Studies in Cognitive Growth, A collaboration at the Center for Cognitive Studies*. John Wiley & Sons, Inc., New York, NY, USA, 1966.
8. Dourish, P. *Where the action is: the foundations of embodied interaction*. MIT Press, Cambridge, MA, USA, 2001.
9. Fels, S., Gadd, A. and Mulder, A. Mapping transparency through metaphor: towards more expressive musical instruments. *Organised Sound* 7, 2 (2002), 109-126.
10. Girouard, A., Solovey, E.T., Hirshfield, L.M., Ecott, S., Shaer, O. and Jacob, R.J.K. Smart Blocks: a tangible mathematical manipulative. In *Proc. TEI 2007*, ACM Press (2007), 183-186.
11. Goldin-Meadow, S. *Hearing Gesture: How Our Hands Help Us Think*. Harvard University Press, Cambridge, MA, USA, 2003.
12. Hashagen, A., Büching, C. and Schelhowe, H. Learning abstract concepts through bodily engagement: a comparative, qualitative study. In *Proc. IDC 2009*, ACM Press (2009), 234-237.
13. Hurtienne, J., Weber, K. and Blessing, L. Prior Experience and Intuitive Use: Image Schemas in User Centred Design. *Designing Inclusive Futures*. 2008, 107-116.
14. Jensenius, A.R. Action - Sound; Developing Methods and Tools to Study Music-Related Body Movement. PhD thesis, University of Oslo, 2007.
15. Johnson, M. *The Body in the Mind: The Bodily Basis of Meaning, Imagination, and Reason*. Chicago Press, Chicago, IL, USA, 1987.
16. Juntunen, M. and Hyvönen, L. Embodiment in musical knowing: how body movement facilitates learning within Dalcroze Eurhythmics. *British Journal of Music Education* 21, 2 (2004), 199-214.
17. Lakoff, G. and Johnson, M. *Metaphors we live by*. University of Chicago Press, Chicago, IL, USA, 1980.
18. O'Malley, C. and Stanton Fraser, D. Literature Review in Learning with Tangible Technologies. 2004. <http://www.futurelab.org.uk/resources/documents/>.
19. Parreren, C.F.V. and Carpay, J.A.M. *Sovjetpsychologen aan het woord*. Wolters-Noordhoff, Groningen, The Netherlands, 1972.
20. Piaget, J. *The origins of intelligence in children*. International Universities Press, New York, USA, 1952.
21. Price, S., Falcão, T.P., Sheridan, J.G. and Roussos, G. The effect of representation location on interaction in a tangible learning environment. In *Proc. TEI 2008*, ACM Press (2008), 85-92.
22. Price, S., Sheridan, J.G., Falcao, T.P. and Roussos, G. Towards a framework for investigating tangible environments for learning. *International Journal of Arts and Technology* 1, 3/4 (2008), 351 - 368.
23. Rimé, B. and Schiaratura, L. Gesture and Speech. In *Fundamentals of nonverbal behavior*. Cambridge University Press, New York, NY, USA, 1991, 239-281.
24. Smith, A.C. Simple tangible language elements for young children. In *Proc. IDC 2009*, ACM (2009), 288-289.
25. Thompson, K. The value of multiple representations for learning about complex systems. In *Proc. ICLS 2008, volume 2*, (2008), 398-406.
26. Ullmer, B. and Ishii, H. Emerging frameworks for tangible user interfaces. *IBM Systems Journal* 39, 3-4 (2000), 915-931.
27. Zigelbaum, J., Millner, A., Desai, B. and Ishii, H. BodyBeats: whole-body, musical interfaces for children. *Ext. Abstracts CHI 2006*, ACM Press (2006), 1595-1600.
28. Zuckerman, O., Arida, S. and Resnick, M. Extending tangible interfaces for education: digital montessori-inspired manipulatives. In *Proc. CHI 2005*, ACM Press (2005), 859-868.