Exploring Ambient Sound Techniques in the Design of Responsive Environments for Children

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ABSTRACT

This paper describes the theoretical framework, design, implementation and results from an exploratory informant workshop that examines an alternative approach to sound feedback in the design of responsive environments for children. This workshop offers preliminary directions and models for using intensity-based ambient sound display in the design of interactive learning environments for children that offer assistance in task-oriented activities. We see the value of this research in developing a more cohesive and ecological model for use of audio feedback in the design of embedded interactions for children. The approach presented here takes the design of multi-modal feedback beyond being experiential, to one that supports learning and problem solving.

Author Keywords

Children, sound feedback, interaction, responsive environments, participatory design, collaboration

ACM Classification Keywords

J.5 [Arts and Humanities] H.5.2 [information Systems]: interfaces and presentations

INTRODUCTION

Auditory feedback is an important part of many educational technologies and computing systems designed for children. It is especially important in tools and systems designed for blind and visually-impaired children [9, 14, 15, 17]. Auditory approaches have recently been applied in educational interfaces to teach mathematics and geography [14, 15]. Learning environments and technologies for children have moved beyond the computer interface and into tangibles, mixed-reality, virtual reality, ubiquitous computing, and embedded interactions in responsive environments. Designing multimodal interfaces for non-desktop systems requires a deep understanding of how each modality can be utilized to create immersive, ecological and intuitive interactions. Visual, tangible, and auditory displays are meaningful when they support the ecology of a system. A system is ecological when the elements within it are balanced and contribute to a high fidelity, information-rich environment [6, 20].

In traditional interface design sound often takes a secondary role to visual presentation. It is often designed without a robust perceptually-based model or a holistic understanding of its role within a system [6]. Short signals and alerts usually constitute the majority of sound feedback in traditional interfaces. While they provide useful confirmatory feedback for the user of desktop systems, they are insufficient when inserted into a complex, physical interactive environment. As a new phenomenon, the potential of responsive environments is only now starting to be explored. Responsive environments are complex spatial and multimodal contexts, which require more holistic, ambient and ecological approaches to sound design than desktop systems. Interactions in responsive environments are embodied, and system feedback is seamless and embedded within multi-modal displays. For this reason, we feel that responsive environments must naturally be grouped together with developments in tangible and embedded interactions.

To create ecological embedded systems of sonic feedback we could look for clues in the natural sound environment. In the physical world, sound is constant and ambient, and we have to dynamically negotiate our attention to it and our interpretation of it. Soundscapes are made up of many sounds in interplay with each other. These include ambient sounds that are present most of the time, sound signals that attract attention, and soundmarks, which characterize acoustic spaces [20]. All of these elements together contribute to an environment's acoustic and information ecology.

Some researchers have focused on developing "ecological" auditory displays [6, 20]. However, there is little work [4, 11, 14] that explores the design of complex auditory displays for children's interactive technologies. The modes

of display in children's learning environments need to incorporate both the way children use their senses in the natural environment, and take into account their age-dependent perceptual and cognitive abilities. The goal of this research is to propose and begin to explore a theoretically informed and empirically based model for how sound can be used as a feedback mechanism. Our research focuses specifically on responsive environment contexts designed for children, aged eight to 12. In our model, sound (auditory displays) is used to support children in task-solving and related learning activities. This is the first known attempt to develop a model which uses auditory feedback in this way and which is specifically tailored to children's developmental needs and abilities.

The model we propose uses sound feedback as an ambient display that changes dynamically along an intensity gradient in order to communicate progress state to children in task-oriented activities. This type of approach provides a consistent and reliable source of communication with children instead of just responding to actions with positive or negative feedback. If interpreted correctly, children would know not only *if* they are on a right track within a certain task, but also, *how far* along they are to completing it.

In this paper we propose that an intensity-gradient auditory feedback model can support children in task oriented activities and is particularly well-suited to the embodied nature of responsive environments. We describe an empirical study designed to explore the utility of this model with children. The study was designed as an informant-based [16] design workshop where children participate in geographic map identification tasks. We use an intensity gradient of musical sound as the primary channel of feedback to support task completion. Involving children in the role of informants in this user study allowed us to observe their behavior and performance, as well as solicit their comments about the effectiveness of our proposed model. We present and discuss preliminary results from our empirical study and suggest emerging design concepts. We conclude with suggestions for future investigations about how sound can be used in responsive environments for children.

BACKGROUND
Children's developmental abilities and limitations must be considered in the design of interfaces targeted to them [1, 3]. In an auditory feedback system based on our model, children have to interpret the meaning of sound changes, which are conceptually unrelated to the activity, and then coordinate their actions to reflect this understanding. Based on previous research exploring the effective design of an ambient intelligent play environment for adults (called socio-ec(h)o), we found that sound intensity gradients were a promising approach for communicating progress information to players in immersive, ambient-intelligent

environments [5, 21]. We extend our previous work to explore these concepts with specific regard to children users and their abilities to perceive, understand and relate auditory feedback to accomplishing a task.

The development of the model was informed by foundational research in children's cognitive and sensory developmental abilities related to auditory perception. In addition, we surveyed information from music education theory for children. We were also informed by previous design research developing alternative interfaces and environments for children with and without visual disabilities. Finally, our model builds on existing work from the field of sonification.

Auditory Perception and Cognitive Development
Research describing children's abilities to perceive sound relative to their level of cognitive development can be found in literature on music education; the psychology of auditory perception; and developmental psychology. The research of Morrongiello [12] and Gromko [8] support our proposal to use sound to augment responsive environments for children. Their research describes investigations of children's ability to trace graphic listening maps. Graphic listening maps are print representations of musical structure and form, and include dynamic and temporal elements. In their studies, elementary school children identified graphic listening maps in three conditions of involvement: passive attention to map during playback of classical music; physical tracing of the map while listening; and embodied interaction with the map in the form of choreography. Results showed that accuracy of reading listening maps increased in direct relation to the level of physical engagement (i.e., embodiment) with a task [8] and that accuracy was dependent both on musical training and overall cognitive development [18]. The findings of this work support the idea of using responsive environments augmented with sound as an appropriate environment for children's active learning. Responsive environments provide the kind of physical, active engagement that clearly aides children's sensory and cognitive perception and task performance.

Empirically based research in psychological and neuro-physical development has demonstrated that basic auditory perception and sound localization skills develop as early as the sensory-motor stages of development (birth to age two) [9]. However, there are some pronounced age and developmental differences in the perception of subtler sound components. For example, perception of timbre and sound envelope [18], perception of musical form and graphical representations of sound [8], and frequency and temporal resolution [9] develop slowly with age. Hartley *et al*. [9] found through empirical studies that while frequency resolution skills reach adult performance at six years of age, temporal resolution of the same quality does not develop until the age of 10. These results informed an audio display

approach for children between the ages of eight and 12, where feedback is represented with intensity gradients of sound. Children in this age range have full frequency, tonal and temporal resolution [18]. They have well developed spatial skills, some abstract thinking skills [7], and are capable of approaching tasks with more sophisticated strategies than younger children [10].

Sound in Interfaces Designed for Children

There is a large array of uses for sound in computerized, tangible and virtual interfaces for children depending on children's ages, abilities and project objectives. For example, in her project 'ensemble' Anderson explores young children's understanding of sensors (i.e., cause and effect) by creating an environment where children, aged four and five, can affect continuous change in MIDI sounds by use of hidden sensors [2]. While this activity is active and embodied, the purpose of sound is for display and composition only. It does not communicate meaningful information to children beyond the reflection on changes they elicit.

In contrast, interfaces and systems developed for children with visual impairments require alternative modalities to represent elements that are normally experienced through vision. For example, they may use audio displays, tangibles and textures to represent space, feel, pictures, maps, characters, numbers, combinations, motion and navigation. Several projects use sound displays and feedback in prototypes for blind children [11, 14, 15, 17]. *AudioMath*, specifically, uses sonic feedback to represent basic mathematics concepts to blind children. The *AudioMath* interface has virtual, tangible and spatial components. Children are asked to identify numbers and perform mathematical actions based on short-term auditory memory. While the interface is information-rich, the sound feedback is limited in its quality and array of representations, and does not *guide* children to the right answer, only confirms when they arrive at it.

The creators of *BAT: the Blind Audio Tactile Mapping System* [14] have taken the auditory interface route further by creating a rich, narrative, audio interface for exploration of geographical maps. When a participant scrolls over the map, a dynamic system of sonification guides them through the map. Movement triggers the system to play local soundmarks and recorded environmental sounds in conjunction with abstract auditory icons that signify major cities, distances between locations and other contextual information.

Sound spatialization in virtual audio is also a popular technique used in the design of interfaces and tangibles for blind and visually-impaired children [11, 17]. A prototype project for children called *World Aloud!* situates a child user within a space and provides spatialized audio feedback which guides them to orient themselves. *The Tangible*

Pathfinder uses a similar approach of localized cues to aide pathfinding navigation for the blind. Yet many sonic interfaces such as *BAT* and *The Tangible Pathfinder* limit auditory information to single-sound, confirmatory-feedback displays. They do not result in the kind of full-bodied, rich soundscape that children might find enjoyable, immersive and informative.

To extend the kind of experiences that are possible for children in responsive environments, we envisioned an auditory display that was immersive and ambient as well as perceptually and cognitively appropriate for children. To achieve this requires a feedback system that supports the acoustic and information ecology of a physical space and provides directive feedback.

SONIFICATION

Our intensity-based auditory feedback model draws on previous work in the field of sonification. Sonification is a way of representing data using a continuous stream of sound driven by changes in values that results in an audible difference in the sound. Sonification results in an auditory feedback model that is both ambient and informative and can direct actions. It is used in environments where large sets of information need to be analyzed hands-free or vision-free [22]. Research in sonification provides some guidelines in cognitive, conceptual and perceptual mapping of information to sound, which inform our model.

Intensity-Based Audio: Lessons from Sonification

Variations in the context and complexity of human activity preclude the development of a universal prescriptive system of design guidelines for data sonification [22]. Research does provide us with specific aspects of sonification which must be considered in developing a model for sound feedback for children.

Data mapping refers to the choice of which data parameter is mapped to which sound variable. For example, we could map temperature to pitch, or to tempo. These design decisions should attempt to balance conceptual and perceptual associations of data and sound parameters. *Scaling* refers to the range between minimum and maximum value that a sound parameter will gradate between, driven by incoming data. Even though humans can perceive fractal relationships between harmonic tones (i.e., we can discern that one tone is an approximate amount higher than other), there isn't an inherent sense of a scale in any a particular sound. *Polarity* refers to the direction of gradient of change. An example of positive polarity is when an increase in temperature is mapped to an increase in pitch. An example of negative polarity is when an increase in volume is mapped to a decrease in tempo. Non-intuitive mappings may confuse users and result in inaccurate comprehension of information. Positive polarity is considered to be more intuitive than negative polarity [22].

There are several major sound parameters that can be dynamically varied in a single sound. These are: amplitude (i.e., volume); frequency (i.e., pitch); timbre (e.g., soft/harsh); and phase (i.e., timbre/rhythm). Lessons from sonification suggest that the most intuitive mappings of information to sound rank as follows: amplitude; pitch; tempo and finally timbre.

INTENSITY-GRADIENT AUDITORY FEEDBACK MODEL FOR CHILDREN

We propose a model that is based on the metaphor of the popular children's game of "hot and cold." Our approach extends this feedback model to mapping a sound intensity gradient directly to a progress gradient of a task. In our model, continuous sound feedback takes the place of discrete spoken word. Our framework uses several major sound parameters: amplitude, pitch, timbre and tempo. Each can be varied according to the progression of the task. For example, if a child is moving away from a solution to a problem then a low intensity sound can be displayed. If they move towards a solution or become close to completing the task, then a gradually rising intensity sound can be displayed (see Figure 1). When a child reaches the final goal or completes the task, a "reward" sound is displayed. This form of final confirmatory feedback was found to be important in conjunction with ambient sound in the responsive environment of socio-ec(h)o [5, 21]. This model could be mapped to any play or learning task-based activity in which children make incremental progress. The model results in a dynamically changing embedded soundscape that is informative and directive.

EXPLORING THE MODEL WITH CHILDREN

We designed a workshop with children in order to explore and refine our intensity-based auditory feedback model and address two main research questions:

1) Can children interpret continuous intensity-based auditory feedback and use it to solve a task? 2) Are there differences in how children perceive different approaches to representing intensity (e.g., pitch-based, timbre-based, tempo-based) and how could we investigate them? The first question has three parts: Can children perceive changes in the sound? Can children interpret these changes as going up or down along an imaginary gradient? Can children meaningfully adjust their actions with regard to the task in response to the intensity-based auditory feedback? For the second question, we hypothized that intensity changes in amplitude and pitch may be the easier to perceive than changes in timbre and tempo. To explore this question, we tested children's ability to accomplish the same activity using different techniques of change. We used response time to try and get at get a possible difference.

We required an activity that involves incremental progress towards a goal, which could be mapped to a sound intensity gradient. Research in music education suggested that the

activity should be physically oriented, engaging, familiar and fun. We also wanted to create a situation where children would take turns solving a task so they could work individually but be surrounded by friends.
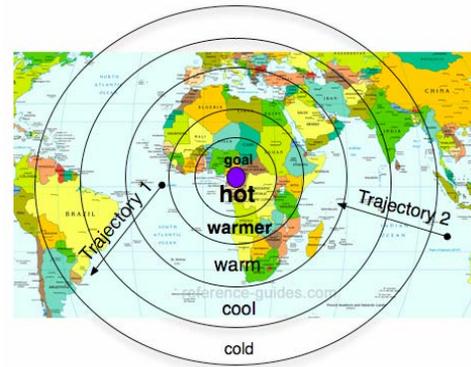

Figure 1. Model of the world map indicating areas of low, medium and high intensity, as well as two sample trajectories

Activity

A geography trivia game meets these constraints. We created this game using a large-scale paper map of the world (see Figure.2) and a wood pointer for tracing. The task was to find a set location using only intensity-gradient feedback for direction. Each child chose one of 10 game question cards, which contained questions on world geography. All questions were made-up to ensure that no one would know the answer. That is, we wanted to isolate sound as the only factor determining success. If we had used questions with real answers, then a child might have known the answer without directive feedback, which would have confounded our results. Answers to the questions were physical locations on the map (e.g., countries, cities, specific ocean areas). The child had to read the question and explore the map to find the right location, keeping the pointer touching the map at all times. While it was possible that a child might find the right location by accident, it was unlikely since locations were points or small areas rather than large areas (e.g., London). In this way, children were dependent on the auditory feedback to find the correct location.

Auditory Feedback

In the workshop we used three different instruments to explore different intensity representations (see Table 1). The instruments we used for audio display were a kazoo, a set of egg shakers and a set of clave sticks (see Figure 2). A triangle was used to generate the final reward sound. Because we wanted to run a low-tech workshop, we were somewhat constrained in our ability to isolate certain sound parameters and test their effectiveness as feedback. We found that any sound-making tool that is operated manually will contain amplitude shifts just as a result of physical

effort. Thus amplitude shifts were a constant element in all three approaches to auditory feedback.

Mapping Sound to Activity

Based on our model, sound feedback had to support progress in the map activity. This required mapping a progress gradient along an auditory intensity gradient. A child's physical interaction with the map and pointer had to be analyzed in incremental stages with respect to the spatial characteristics of the map. With a 2-D physical object such as a map, and a goal state that is a discreet location, areas of intensity can be situated using polar coordinates to map out concentric circles from the goal (see Figure 1). The same intensity is generated anywhere along an area defined by a specific concentric circle. Intensity increased or decreased directionally with respect to the relative starting point.

Figure 1 illustrates this approach. The two sample trajectories represent the movement of the pointer tracing over the map. Trajectory 1 begins close to the goal. The intensity would decrease along the trajectory because the direction of the path is moving away from the goal. Conversely, Trajectory 2 begins farther away from the goal. The intensity would increase along the trajectory because the direction of the path is moving towards the goal. The relative starting sound intensity reflects the starting point. For example, Trajectory 1 starts off at a higher intensity than Trajectory 2 since it begins closer to the end goal.

Workshop Sessions

This workshop was held in a common room of a neighbourhood apartment complex. The participants were children, aged eight to 12 from the local community. There were four boys and six girls. They all had some musical training in classical musical instruments – violin, guitar, piano. Two sessions were held. Each lasted approximately 35 minutes. The sessions were recorded using audio and video. There was one facilitator, one observer and two assistants.

In order to understand more about children's interpretation of intensity-based sound feedback we separated the workshop in two distinct sessions. In the first, the facilitator was the soundmaker. She provided continuous feedback while an individual child traced the map searching for the

Audio Display	Approach to Intensity	Polarity
Kazoo	Pitch Shift (Complex Tone) + Amplitude	Positive
Clave sticks	Tempo Shift + Amplitude Clean Timbre	Positive
Egg Shakers	Tempo Shift + Amplitude Rough Timbre	Positive
Triangle	Confirmatory Feedback	N/A

Table 1. The table above shows the three instruments we used in the workshop and the respective approaches to intensity.

correct location. Each of the three kinds of intensity feedback was used in turn to guide children during the task. In the second session, children worked in pairs. One child sonified a secret location of their choosing, while he second child tried to find that location using the sound guidance. They were given the choice of using any of the three instruments (i.e., kazoo, clave sticks, egg shakers). They were not given any other specific instructions on how to represent intensity.

Data Analysis

The goal of the workshop was to observe how children used gradient audio feedback with regard to a task; and if, and how, the different approaches to feedback impacted children's ability to perform the map location task.

Session one explored how children interpreted three kinds of continuous intensity-based auditory feedback and used it to solve a task. Audio data was analyzed to isolate children's verbalizations about the sound feedback. We identified instances where they described the sounds they heard. We examined the words they used to describe sound in order to determine if they correctly identified the type of change and perceived differences in intensity. Two operational concepts that we specifically looked for and coded in the workshop were trajectories (directional tracing patterns); and scaling (*how intense* sound feedback was as a measure of distance to goal). If a child moved from point A to point B, feedback intensified, and they did not return to point A, we interpreted this as both a successful understanding of sound intensity, and its translation into game actions. We then looked for whether they continued on the right trajectory and reached the goal, either directly, or through exploring and rejecting other trajectories. Understanding of scaling also played a role in this activity. Correct judgment of distance to the goal required that a child understood scaling – by *how much* a sound increased as a measure of *how close* the goal is.

We also recorded time of completion for different types of audio display to explore if different approaches to intensity improved performance. As well, we explored this topic in the post-workshop discussion.

In the second session we looked for the same concepts as in session one – understanding of sound intensity exhibited through children's physical trajectories over the map. In addition, we looked at the way children themselves performed intensity (in terms of scaling, polarity, and mapping to trajectory). Through audio analysis we examined and coded the temporal and dynamic patterns of the sound feedback children provided for their game partner. This helped reveal their understanding of how continuous intensity-based feedback mapped against a progress gradient of a task.

Figure 2. . Question cards, kazoo, egg shakers and clave sticks, and paper mapgame

WORKSHOP RESULTS

Overall children enjoyed the game and found the sound feedback engaging and fun. They understood the game concept right away and related the metaphor of "hot" and "cold" to sound feedback without any additional explanation or training.

Understanding of Intensity-Based Sound

In order to examine children's understanding of sound intensity feedback we counted the number of exploratory trajectories children took, and compared it with the number of correct and incorrect trajectories. Each time they would stop and start tracing with the pointer counted as a discreet exploratory trajectory, because it generated a new starting point. Correct trajectories were ones that led towards the goal and incorrect ones led away from the goal. We counted some trajectories only as exploratory because it requires a certain number of explorations to "get on the right track."

Eight out of 10 children made more correct trajectories then incorrect ones. Initially, we had observed ambiguity in whether children truly grasped and perceived the changing intensity of the sonic feedback. Whenever they made incorrect trajectories *after* having found a correct one, we thought that they did not grasp the relationship between intensity and physical trajectory. However, the ratio of correct to incorrect trajectories does not confirm this. Another explanation is that children understood trajectories and perceived sound intensity correctly, but failed to estimate relative distance to the goal.

Scaling as Perception of Distance

Children's comments in the post-workshop discussion demonstrated that scaling was difficult for them to interpret. One child compared the workshop game to the traditional "hot" and "cold" game. They said, "This [workshop game] is harder, because it's not like they can say 'burning hot' and you'd know you're right next to it. You have to decide which way to go." What this alludes to is a common difficulty when interpreting abstract feedback – there isn't an inherent scaling system that one can rely on. Determining if a sound is increasing or decreasing in

intensity seemed intuitive to all children. However, estimating *by how much* and translating that to distance between current position and final goal was more difficult. Using a discrete and unique "reward" sound (the triangle) to pinpoint the goal emerged as a way to alleviate this difficulty.

Polarity of Intensity Gradient

Children had an intuitive positive polarity mapping of progress to sound intensity. Both in the warm-up session and in the post-workshop discussion, children expressed their understanding of "cold" being a low sound and "hot" being a high sound. One child elaborated on low and high being musical notes. However, these terms could also be interpreted in terms of amplitude.

Pair No	Audio Display	Feedback Progression	Trajectory/Location Updating
1	Clave	Slow/Quiet - Medium/Steady - Fast/Loud	Trajectory-based
2	Clave	Slow/Steady - Fast/Loud	Location-based
3	Clave	Slow/Quiet - Fast/Loud	Location-based
4	Shakers	Quiet – Medium – Fast/Loud	Location/Trajectory
5	Clave	Quiet/Silent Medium – Fast/Loud	Location/Trajectory
6	Clave	Quiet/No intensity – Steady - Loud	Location-based
7	Clave	Quiet Medium/Steady –Fast/Loud	Location/Trajectory
8	Clave	Quiet/Silent – Louder – Very Loud	Location/Trajectory
9	Shakers	Quiet/Silent - Medium– Fast/Loud	Location-based

Table 2. Coded results from session two, focusing on how children represented intensity gradients themselves.

Different Approaches to Sound Intensity

Our second research question asks whether different approaches to sound feedback would affect perceivability, and thus performance. In session one children found the answer to their trivia question in an average time of one minute and 10 seconds with a standard deviation of 55 seconds. Time of completion was fastest with a pitch-based feedback (the kazoo), followed by tempo-based feedback (clave) and timbre/tempo-based intensity (egg shakers). This order is exactly how children themselves ranked ease-of-perception of the different approaches from session one.

Children-generated Sound Intensity Gradients

In the second session, five pairs of children (a total of nine game instances) took turns sonifying locations on the map for each other. Instead of tracing trajectory paths on the map, we examined each child's approach to representing

intensity as a measure of their understanding of gradient sonic change. This included their choice of feedback approach (pitch, tempo, timbre/tempo), the dynamic sound envelope of display, and the inferred mapping between sound feedback and trajectories/locations on the map. From our overall findings it was evident that children had a detailed and acute perception of intensity-to-trajectory mappings around a discreet location (usually within a small perimeter of the goal). However, they did not think of the whole map as having degrees of intensity and thus they did not adjust onset intensity relative to a starting point and its position from the goal. Their use of scaling exemplifies this point (see Table 2). Their intensity-generated feedback sound lacked continuous gradation and instead contained three discreet stages: low/no feedback; medium unchanging feedback; and very intense feedback.

Children-generated Approach to Scaling

When one child was tracing an area that was far from the goal the other child tended to provide minimal or no intensity and did not change the intensity significantly when the exploring child moved the tracer in any direction. However, when the player reached the small vicinity of the goal, sound feedback intensified and became very carefully mapped to trajectory, and much more gradual. There was a drastic difference between "warm" feedback and "hot" feedback – much more so then was provided in session one by our facilitator. As one participant commented to another player regarding scaling– "No, it has to go like 'tin-tin-tin-tin' (said very fast, imitating the "maximum" intensity of the clave sticks approach).

Children-generated Audio Reward

Children also started adding the word "ding" on their own (imitating the triangle), in order to signify when the goal was found. This speaks to the idea that they need to both receive and provide a discreet reward upon solution of the problem.

DISCUSSION AND FUTURE WORK

Our intensity-gradient auditory feedback model was received well in the context of the activity we designed – an embodied, spatial trivia game. Children thought it was fun and found the flow of the game appropriate. Children reported that it was not so easy as to be boring and that it was not too hard as to be frustrating. Through the workshop we were able to explore our research questions, and our findings led to specific design ideas about representing progress through sound. Some of these ideas are summarized in a list in the next section. Most importantly, we learned that intensity-based sound feedback worked well in representing progress gradient for a task. Children found sound intensity easy to perceive and useful in performing a specific cognitive/spatial task. We also learned which concepts children have most difficulty with. Perception and interpretation of scaling was one. Children

also had a hard time understanding that audio feedback is a system encompassing the entire progress gradient, and not just the last steps to solving the task. We confirmed the effectiveness of some design decisions such as using a positive polarity, using pitch and tempo-based sound intensity approaches; and providing a discreet reward. The design workshop also helped us begin to develop tighter definitions of operational terms (trajectories, distance, location) in the context of a multimodal embodied activity.

One of the most important outcomes is that we were able to separate concepts of intensity approach, scaling and polarity, and look for their manifestations in the workshop. Specifically, the activity of having children represent intensity to each other helped elucidate issues of continuous sound feedback. We were able to confirm that positive polarity was understood by children, and that amplitude and pitch-based feedback were easier to perceive than feedback based on tempo or timbre. Based on our proposed model and workshop results we articulate the following recommendations for future work in exploring and designing intensity-based feedback for children:

- Use positive polarity in mappings;
- Amplitude, pitch and tempo are all effective ways of representing intensity (in order of perceptual ease);
- Children have difficulty understanding and representing scaling;
- Within discreet locations, children can perceive and construct the mapping of trajectories and distance to sound intensity;
- Children have difficulty understanding and translating intensity to the entire progress gradient of the activity.
- Children need a discreet reward sound upon completing the task.

CONCLUSION

In this paper we begin to build both a theoretical framework and an exploratory approach to supporting an alternative sound feedback for children. The theoretical model links sonification research with children-centered research in constructing a new model for auditory feedback. This model uses sonification techniques of representing information change to represent incremental stages in the completion of a task. Based on our workshop, we offer some leading design ideas for ambient auditory feedback systems for children. This paper adds to the existing research in designing multi-modal sonic environments for children with and without visual disabilities. It offers a novel approach to using auditory feedback that guides and helps children in achieving a task, rather than simply confirming or rejecting their solutions. Our workshop is a step towards developing a more comprehensive framework for the role of sound (auditory displays) in responsive environments targeted specifically to children users. Such a framework would consider sound within the complete

acoustic and information ecology of the system and deliver meaningful feedback.

Future work should include operationalizing and separating concepts of auditory intensity in different contexts. Based on the leads from our workshop, parameter mapping, polarity and scaling of sound must be separated and examined further, especially with regard to different activity contexts, levels of embodiment or tangible interactions, different approaches to intensity, and levels of musical training/sound competence. That way an auditory feedback system can support children's cognitive needs and abilities better. Further studies could also situate activities directly into ubiquitous computing environments and test the approach in these contexts. Findings can also be applied to the design of multi-modal systems for children with visual impairments.

We see the value of such research to be in designing novel auditory environments for children as opposed to traditional computer interface sound effects. This research contributes to understanding the role that sound can play in the design of ubiquitous computing environments for children, aged eight to 12. Such auditory environments rely on a constant, subtly changing ambient soundscape and are more reflective of the natural sonic environment.

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