Designing tangible play objects for toddlers’ open-ended play using multimodal feedback and multisensory stimuli

By: Justyna Karpinska

Supervisor: Martin Jonsson
Södertörn University | School of Natural Sciences, Technology and Environmental Studies
One Year Master Thesis, 30 hp
Media technology | Spring semester 2017
Interactive Media Design program
ABSTRACT
Designing tangible objects for children’s development and learning has been a common theme in the HCI community. However, studies involving designing of tangibles for toddlers’ hedonic interaction and play experiences have been few. This paper explores how toddlers (between one and three years old) behave when interacting with tangible play objects in the context of open-ended play. The aim of this study was to explore how the integration of multisensory stimuli and multimodal feedback in tangible objects can affect toddlers’ play, behaviors and engagement in the context of open-ended play. Furthermore, two play objects called Sound Cubes were developed and used in an interaction study conducted at a preschool in Stockholm. The results presented in this paper suggest that the open-ended play objects provided toddlers with opportunity for multiple manipulations that lead to interesting interactions. Moreover, multimodal feedback and multisensory stimuli created a positive affect on toddlers’ engagement in play.

Author Keywords
Tangible interaction; hedonic interaction; toddlers; multimodal feedback; multisensory stimuli; open-ended play

INTRODUCTION
Children spend most of their time playing. Play is a crucial part of a child’s life because it is directly related to aspects of their development, notably the development of the cognitive domain (thinking) and the affective domain (emotion/feeling) [18]. Toddlers between the ages of one and three years old engage in different types of play. Because children around the age of 12 and 20 months become more mobile, their play opportunities expand. The play becomes more explorative and it is why open-ended materials can promote interesting challenges for children interacting with them [18]. By exploring their surroundings toddlers acquire skills such as cognitive, perceptual-motor, social and emotional [10].

With today’s development of technology, the opportunities for designing children’s play broaden. There are some existing research exploring how tangible interaction can be used in order to explore children’s play opportunities [21] and different types of play and play behavior [19]. However, there has not been much focus on evaluating the outcomes of embedding multimodal feedback and multisensory stimuli in tangible objects, specifically for toddlers. It is also relevant to mention that a great deal of research surrounding children and tangibles focus on how the tangible interaction can support children in their development or learning. Instead, I argue that designing engaging and interesting play experiences can be equally as important to explore, particularly for younger children. While topics of play, games and hedonic interaction for adults are accepted parts of the HCI research community, such topics for children are still considered controversial. Instead the existing perspective is still that design for children should somehow support their development or improve their capabilities in different ways. Therefore, the exploration of hedonic experiences, engagement, and play in relation to children is an interesting topic. It is also particularly interesting how toddlers, as an understudied group of users, respond to such exposure to interactive tangibles and if such designs really vary from traditional interactive toys.

Children change a great deal between the ages of one and a half to five years, both physically and cognitively, as well as in what types of play they engage in [4]. This makes the task of designing for toddlers’ play challenging. When designing for young children, traditional user-centered methods [16] and evaluation methods such as e.g. ladder [22] are not appropriate. Those methods often heavily rely on communication and verbalization, thus excluding toddlers from the process of designing products specifically for them [16]. Since the development of tangible and interactive technologies is more focused on what users do rather than what they say [16], such technologies are great alternatives when designing for children.

Designing for open-ended play in particular, involves many different aspects. Objects designed for such play should be not only age appropriate, gender neutral and interesting but also promote children’s independence and creativity [5]. Overall, the design should be created with the goal of supporting play, the use of imagination and creativity within play. That also involves designing an object that is specific but at the same time simple and understandable, thus leaving room for interpretation and creativity [21].

The contributions of this paper are as following: Firstly, reviewing articles surrounding the topic of tangible interaction design and open-ended play, as well as the topic of various play forms and play types. Secondly, presenting a tangible design, Sound Cubes, built on the idea of designing for open-ended play using multimodal feedback and multisensory stimuli. Lastly, reporting and analyzing findings from an interaction study conducted with toddlers using the Sound Cubes. This paper focuses more closely on toddlers’ engagement in interaction with tangible objects, in particular: how the integration of multisensory stimuli and multimodal feedback in tangible objects can affect toddlers’ play, behaviors and engagement in the context of open-ended play.

RELATED WORK
There are several relevant articles within the field of HCI that explore tangible interaction for children. Although, it is noticeably clear that the majority of the studies focus on children older than three years old, while research surrounding toddlers is sparse. It is also relevant to mention the articles raising interesting qualities in open-ended play and play behaviors and how those theories can be used when designing for children’s play.
Tangible interaction and children

In recent years, tangible interaction is something that has been steadily rising in popularity. The advancement in new technologies has created opportunities for development of, for example, applications that are based on direct manipulation of physical objects as input to digital systems [1]. This has meant that the theories of educators such as Jean Piaget and Maria Montessori, about how physical interaction is key in cognitive development in childhood, could now be applied when designing tangible user interfaces (TUIs) for children [1].

There is a great deal of studies exploring the notion of tangible interaction and how it can affect children’s learning and development [2, 3, 4, 5, 6, 7, 8, 9, 10, 11]. Van Huysduynen [21] and colleagues conducted a study exploring differences in various feedback combinations and particularly how these can influence play opportunities for children in two different age groups; four till six years old and ten till twelve years old. In order to explore these questions, the authors developed interactive objects for open-ended play called MagicBuns. The objects focused on three different feedback modalities: sound, light and vibration, which were triggered by either shaking or rolling the object. The MagicBuns were also able to communicate with each other through infrared communication. The results of this comparative study showed examples of different games the children created with the objects, differences in the effects on younger and older children, as well as explanations of how the different feedback combinations triggered the attention of the children. Concluding the study, the authors presented design guidelines for open-ended play, which will be further explained in the next section of this paper.

Similarly to the work of Van Huysduynen and colleagues, Sridhar and his fellow researchers [19] developed different tangible objects for the context of children’s play. Their study focused on augmented toys and how interactive objects affect play behavior. In order to explore that, Sridhar and colleagues developed SparKubes, a set of tangible objects that use light as their main feedback modality. There were three different groups of SparKubes used in the study; blocks with no inserted features, blocks with interactivity features and black mirror patterned blocks. The study compared children’s use of the three different types of objects as well as analyzed how those affected play behaviors. The results revealed for instance how traditional objects like blocks could potentially become interactive objects for facilitating play.

Open-ended play

De Valk, Bekker and Eggen conducted a study exploring the notion of open-ended play together with students. In the results of the study, the authors define the term of open-ended play as following:

“Open-ended play is play without predefined (game) rules in which players can attach meaning to the design properties and the interactions themselves while playing. Its goal is to trigger a player’s creativity by leaving room for interpretation.”[6]

Open-ended play is by that definition a kind of middle between games with pre-defined rules and open, non-interactive free play. Therefore, designing for open-ended play mainly revolves around finding a balance between the ambiguity and complexity of the design [6]. A design for the purpose of open-ended play should thus be definitive enough in its functionalities and easy to understand while simultaneously leaving room for children’s interpretations and creativity [21].

Van Huysduyen [21] and colleagues presented a few design guidelines for open-ended play when designing for younger (four till six) and older children (ten till twelve). In relevance to this study, only the guidelines for the younger children will be described. These guidelines are as following:

- Provide simple interaction rules in combination with one feedback modality
- Add communication between multiple objects

Following these guidelines, the designer can support children’s imaginative and parallel play as well as create more complexity to the interactions in order to support children’s social skills development [21]. To summarize, designing for open-ended play is grounded in taking a risk and not overwhelming the user with too many functionalities [6].

Play Pyramid and Play Grid

Kudrowitz [13] defined four general forms of play based on Piaget’s stages of cognitive development, which he called: sensory, fantasy, construction, and challenge. These different play forms are described as four edges of a pyramid. A play toy can fall into one or two categories of play, but may also possess aspects of all four categories.

Sensory play revolves around engaging the human senses. It involves for instance the aesthetic of the play object and the physical manipulation it provides. Important parts of this play category are how the play object feels, smells, tastes, sounds or looks like.

Fantasy play is often about make-believe and pretend. The play object within this category stimulates children’s imagination. It puts the child in a state of mind that is out of the ordinary and gives them room for interpretation.

Construction play is about creating things. It revolves around creativity and how the child uses that creativity (e.g. by doodling or creating new words). A play object in this category focuses on allowing the user to create.

Challenge play is about challenging the child’s abilities, both mental and/or physical. This means promoting the use
of fine and gross motor skills as well as mental skills. A play object in this category focuses on challenging the user in different ways.

The Play Pyramid presented above is linked to the play objects. It is the object that creates the opportunity for a certain play or is developed for a certain type of play. The Play Grid on the other hand, developed by Fogh and Johansson [8], focuses on the player. The Play Grid presents four different play types: the Assembler, the Director, the Explorer, and the Improviser.

The Assembler focuses on understanding the physical world. Such a player is searching for an understanding, organization and control of the environment around them. The play might involve building or solving problems.

The Director uses play objects as things to spark their imagination. Their play focuses on role-playing and storytelling.

The Explorer is driven by curiosity and the need for investigation. Their play consists of approaching the play object hand-on, tinkering with it and exploring it from all angles.

The Improviser is driven by spontaneity and intuition. They don’t care much about structure and will follow their own guidance. Their play often consists of elements that they find interesting with no thought for coherence.

The play types presented above draw on two characteristics of the human psyche: extraversion/introversion and agency/communication and how it affects play from person to person. The authors also categorize the players into outer reality (the play object is what it is) and inner reality (the play objects becomes a symbol) as well as agency (focusing on the player’s own rules) and communication (fitting in and creating play rules for specific context).

An action-centric view on tangible interaction
Tangible interaction is very much about actions and how the users perform those actions. Fernaeus, Tholander and Jonsson [7] suggest a broader focus on designing tangibles, wherein instead of focusing on the properties of the TUIs, the designers should aim towards designing qualities of the activity of using a system. Fernaeus and colleagues mean that tangibles create recourses for action and present four such recourses:

1) for digitally mediated action – where the ways of manipulating tangibles can open up the interaction with the digital, thus expanding the navigation in virtual spaces.

2) for perception and sensory experience – where the physical and digital recourses can lead to various sensory stimuli. The interaction between the user and object becomes more subjective and personal.

3) for physical manipulation – where the tangible objects and their physical aspects provide opportunities for physical manipulation

4) for referential, social and contextually oriented action – where tangibles exist in the physical space, thus allowing for more bodily interactions. The interaction space broadens because the interaction does not only happen within the system but also in the physical space around it.

Viewing tangible interfaces from an action-centric perspective can help to create a broader understanding of the tangible system developed, since it does not only focus on technical and design-oriented aspects of the tangible interface, but also on how does aspects integrate with the social, bodily and contextual factors, which are important in the design of tangible systems [7].

DEVELOPMENT PROCESS
The development of the Sound Cubes prototypes involved several different aspects and followed a research through designs process. The aim was to create a tangible open-ended play object that would be engaging for toddlers. Steps where taken in order to gather information about the target group as well as technologies most suited for the study. In the following section, an overview of the development process is presented.

Pre-study
To gather more information about the target group and their different behaviors and skills, a pre-study was conducted.

The pre-study was carried out with ten children aged between one and three years old (or more specifically between 21 and 34 months old) at a Montessori preschool in Stockholm. The prototype used for this study was constructed with the Makey Makey technology and with the goal of creating a multisensory way of interaction during a learning exercise.

The prototype (See Figure 1 on next page) focused on three sensory aspects: tactile, visual and auditory. The interaction revolved around children touching real physical fruit (tactile) and receiving feedback in the forms of representations of those fruit on screen (visual) as well as the computer naming the fruit (auditory).

Figure 1. Makey Makey Prototype
The study showed that younger children (under the age of two years old) have a harder time understanding the connection between the physical objects and the
representations on screen. These results are similar to Bruikman and colleagues’ [3] where they concluded that children under the age of two and a half years old seemed not to understand or only partly understood the mapping between the physical and virtual representations [3].

The children were very explorative when interacting with the prototype. The younger children in particular were often more interested in exploring the fruit or the alligator clips attached to the prototype rather than using the prototype in a learning fashion. Physical manipulation was discovered to be an essential aspect of the interaction and something important to consider when designing for toddlers.

Sound was another aspect of the interaction that was particularly engaging for children. It is worth to mention that there is a noticeable difference in children aged 21 months or 34 months, but both the older children and the younger ones found the auditory feedback to be engaging. The older children would repeat what the computer would say while the younger children liked to touch the fruit as many times as possible to receive the auditory feedback repeatedly.

**Design process**
The design process began with creating a general list of design criteria or goals for the final design. The criteria created were based on earlier research as well as on results from the pre-study. These criteria were following:

- Multimodality – the design can be used in several different ways
- Use of physical materials and manipulation of physical materials in some way
- Multimodal feedback and multisensory stimuli
- Minimal to none physical to screen connection

The design process involved a long period of time devoted to brainstorming, sketching and prototyping. Different types of technologies were tested, such as Makey Makey¹, Little Bits² and Micro:Bit³, in order to find a technology suitable for the initial design idea.

**Designed object**
The final Sound Cubes prototypes consist of two cardboard boxes covered with colorful foam clay material for sturdier front as well as for equipping the prototypes with a more aesthetic look. The inside of the boxes include programmed Micro:bits, alligator clips, copper tape and small speakers. A hole has been cut out in the bottom of the boxes where the speaker is mounted. Each box also has a hole for the LED Micro-bit display. A closer look at the construction and technology of the Sound Cubes prototypes can be viewed in Figure 2.

![Figure 2. Construction and technology](image)

The foremost motivation behind the final design of the prototypes was the goal of creating an interactive object that is not connected to the screen. Since the pre-study showed that toddlers had a harder time grasping the connection between physical and digital representations, it was important to create an object with minimal to none screen based interactions. The pre-study also showed how sensitive the children were to sound. Sound and color are some of the things that children are most sensitive to, which is why the two feedback modalities are great at attracting children’s attention [3]. Therefore, the functionalities within the Sound Cubes prototypes heavily rely on sound feedback. The results of the pre-study were crucial in the process of developing the Sound Cubes prototypes.

Another part of the motivation behind the design was partly based on Zuckerman et al.’s [24] general design criteria for designing tangible interfaces. These criteria include modularity, multi-sensory representations, coincide input/output and synchronous input/output [24]. The development of the Sound Cubes prototypes mainly focused on the last two criteria. It was important to create an object where the interactions would arise in the same space and at the same time, meaning if a child interacted with the prototype, the interaction would occur with no additional graphical user interface (GUI) needed and the feedback and manipulation would happen simultaneously. Zuckerman et al.’s guidelines also include multi-sensory representations. These multi-sensory representations (such as light, sound) [24] could be used to support different types of interactions.

Finally, physical manipulation was a crucial part of focus during the development process. Toddlers’ play is often driven by their physical abilities [21] and focuses on simple manipulation [4]. Consequently, the design of the prototypes would provide simple physical manipulation.

The Sound Cubes prototypes were developed as tangible objects for open-ended play. Therefore, the functionalities possessed by the objects are simple as means for opening up the interactions to children’s own imagination and

¹ [http://www.makeymakey.com/](http://www.makeymakey.com/)
² [https://littlebits.cc/](https://littlebits.cc/)
³ [http://microbit.org/](http://microbit.org/)
creativity. The prototypes are designed with the use of multisensory stimuli and multimodal feedback. In this case the multisensory stimuli are tactile; the opportunities for physical manipulation, audible; the different sounds the cubes emit appealing to the child’s hearing, and visual; the use of a LED-screen with changing figures. The feedback modalities are sound and visual. For overview of the design and functionalities see Figure 3 and Table 1.

![Figure 3. Sound Cubes a) Front view b) Bottom and side view](image)

<table>
<thead>
<tr>
<th>Input</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shaking</td>
<td>Changes figures on LED-display</td>
</tr>
<tr>
<td>Tilting (up, down, right, left)</td>
<td>Emits various tones</td>
</tr>
<tr>
<td>Tapping or grasping sides</td>
<td>Emits a melody</td>
</tr>
<tr>
<td>with copper tape</td>
<td></td>
</tr>
<tr>
<td>Connecting both cubes by</td>
<td>Both cubes emit melody</td>
</tr>
<tr>
<td>copper tape sides</td>
<td></td>
</tr>
</tbody>
</table>

**Table 1. Sound Cubes functionalities**

**STUDY**

An interaction study was conducted to examine more closely how multimodal feedback and multisensory stimuli in tangible objects can affect toddlers’ play, behaviors and engagement in the context of open-ended play.

**Set-up and participants**

The study was carried out in a Montessori preschool in Stockholm, Sweden. The participants were individually or in groups of two or three called into a smaller, secluded room where the study was set up. A teacher and one researcher who filmed the interactions were present during the sessions. Since the study revolved around open-ended play the interaction study was semi-structured. The participating children could interact with the Sound Cubes freely with minimal teacher interferences or instructions.

The study was carried out with eight children aged between one and three years old (or more specifically between 21 and 34 months old). Permission for the children’s’ involvement in the study was granted by their parents.

**Data gathering and analysis methods**

In order to analyze the study sessions and to be able to gather the results, video recordings were used. Using video recordings for interaction studies has shown to be a great method since it captures how different aspects such as talk, the human body, artifacts or local environment elaborate one another during an interaction [9].

The analysis of the interaction study was three fold. Firstly, the recordings were analyzed in order to find different forms of interactions between the children and the Sound Cubes. Secondly, those interactions were evaluated using an action-centric view on tangible interaction [7]. Lastly, the information gathered was analyzed by applying some characteristics of the Play Pyramid [13] and Play Grid [8] onto the interactions observed.

**RESULTS AND ANALYSIS**

**Forms of manipulations**

Since the Sound Cubes prototypes leave room for interpretation and exploration the interactions varied from child to child. Some children created games like rotating the cubes using the table or passing the cubes back and forth, while others explored the construction and functionalities by shaking the cubes, trying to find the speakers or open up the cubes to look inside. Noticeably, the interactions that occurred during the entire interaction study were many. However, some forms of interactions and manipulations of the Sound Cubes were more common, while other more rare and personal. The most common and interesting manipulations are presented in Table 2 (See Table 2) ranking from most common to least common.

**Manipulations**

<table>
<thead>
<tr>
<th>Number of children</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Tilting</td>
</tr>
<tr>
<td>2. Shaking</td>
</tr>
<tr>
<td>3. Poking screen</td>
</tr>
<tr>
<td>4. Opening cubes</td>
</tr>
<tr>
<td>5. Connecting</td>
</tr>
<tr>
<td>6. Sliding across</td>
</tr>
<tr>
<td>7. Rotating</td>
</tr>
<tr>
<td>8. Swaying</td>
</tr>
<tr>
<td>9. Hitting against</td>
</tr>
<tr>
<td>10. Stacking</td>
</tr>
<tr>
<td>11. Knocking</td>
</tr>
</tbody>
</table>

**Table 2. Common forms of manipulation**
An action-centric view on interaction
Applying an action-centric view on interaction [7] when analyzing the data from the interaction study resulted in discovering how the Sound Cubes prototypes and the interactions they provided lead the users to different actions and experiences. Seeing how the design leads to different actions makes the analysis more focused on the interaction between the users and the design, instead of just focusing on the design’s input and output modalities.

Digitally mediated actions
Shaking and tilting are functionalities that use Micro:bit’s accelerometer. When shaking the cubes, the figures on the LED-screen change, which provides an expanded opportunity for navigating the digital part of the prototype by physical manipulation. However, when the children were shaking the prototypes their intentions were usually not to navigate the LED-screen. By shaking the prototypes, the children focused on the auditory feedback. Therefore, the prototypes provided the children with digitally mediated actions, which were not fully carried out by the users.

Perception and sensory experience
The Sound Cubes were developed using multimodal feedback and multisensory stimuli, therefore appealing to children’s different senses. This created personal and subjective interactions. For example, one child would simply shake the prototype in order to emit sounds and listen to them (See Excerpt 1), while another would create a game of rotating the cubes against the table (See Excerpt 2).

Excerpt 1: Listening to sounds
Sequence 1: [Listens to the sound from one cube]
Sequence 2: [Shakes both cubes close to his ears]
Sequence 3: [Listens to both cubes simultaneously]

Excerpt 2: A game of rotating the cubes
Sequence 1: [Grasps both cubes]
Sequence 2: [Starts rotating one cube against the table]
Sequence 3: [Starts rotating both cubes against the table]

Physical manipulation
All resulting interactions involve some sort of physical manipulation. By the physical manipulation provided, the children could choose how they wanted to use the prototypes. Therefore, the children could not only manipulate the Sound Cubes to emit sound or change the displayed figures, but also use the prototypes in much more simpler ways disregarding the sound and visual feedback. This resulted in interactions such as matching the colorful sides to each other or stacking the cubes on top of each other (See Excerpt 3 on the next page).

Excerpt 3: Stacking the cubes on top of each other
Sequence 1 and 2: [The child stacks the cubes on top each other several times]

Referential, social and contextually oriented action
Tangibles are great at creating social interactions, particularly for children because they are more sharable than, for example, a game on a tablet. Bringing the technology out in the physical world creates more opportunities for interactions around the space of the technology [7], thus creating more opportunities for sharable interactions and social experiences. It could be observed how the children used the Sound Cubes in different social contexts. They would, for example, pass the cubes to the teacher, show off different functionalities, try to get the teacher to interact with the prototypes, and show the play objects to each other (See Excerpt 4).

Excerpt 4: Social contexts
Sequence 1: [The child passes the cubes to the teacher]
Sequence 2: [The child shows the cubes to the teacher and another child]
Play Pyramid and Play Grid
The Play Pyramid consists of four different play categories; sensory, fantasy, construction, and challenge, which a play object can fall into [13]. Applying these onto the Sound Cubes can help recognize what kind of play the object engages the children in. However, since its main focus is on the object, the analysis of this interaction study will also be analyzed using the Play Grid theory about the four different play types; assembler, director, explorer, and improviser [8]. Combining these two theories together in the analysis creates a broader understanding of the interactions based on both the play and the player and how does can be linked to each other.

Since not all play categories or play types were recognized during this interaction study, a selected few will be presented and discussed in relation to each other. The sections will also include excerpts as examples.

Play pyramid – Sensory play
During the interaction study sensory play [13] was the dominating play form since the prototypes were developed using multimodal feedback and multisensory stimuli, thus creating a perfect opportunity for sensory play. The children could manipulate the objects physically (relying on their motor skills) and receive visual and auditory feedback, which stimulated their visual and hearing senses. Such multimodal feedback does not only appeal to children’s senses [13], but can additionally provide motivational feedback to behavior [21]. This happens, when a child explores how an interactive object, such as the Sound Cubes, responds to different manipulations of it and then embedding that exploration and interpretation to their play [21]. An example of how the Sound Cubes provided such motivational feedback to behavior can be seen in the excerpt below (See Excerpt 5).

Excerpt 5: Motivational feedback leading to behavior

Sequence 1: [Child discovers that holding the cubes this way emits a melody]
Sequence 2 and 3: [Child repeats the same motion repeatedly and starts dancing to the melody emitted]

Play Pyramid – Challenge Play
The children were very explorative when interacting with the Sound Cubes. Tinkering with unknown objects and exploring their functionalities by physical manipulation can be linked to challenge play. Firstly, trying to, for example, open the cubes (See Excerpt 6) or grasping the cubes in different ways, pose challenges for toddler’s developing motor skills.

Excerpt 6: Opening the cubes

Sequence 1 and 2: [The child tries to open up the cubes to explore the inside]
Sequence 1: [Child discovers that the cube emits sounds when picked up this particular way]
Sequence 2: [Puts the cube back down on the table and laughs]
Sequence 3: [Picks up both cubes in the same motion as in the first sequence]

In the excerpt above (See Excerpt 7), it can be observed how a child figures out one of the functionalities of the Sound Cubes. She recognizes the pattern of interaction that if she tilts the cube a certain way a specific sound will be emitted. The child tries this concept with both cubes and repeats the same motion several times. This results in the play not only being challenging in the physical sense but in the mental one as well.

Play Grid – The Improviser
The Improviser is spontaneous in their play and relies on their creativity [8], which are traits that can be recognized specifically in the different games the children created without prompting from a teacher or researcher. The children’s improvisations for games usually emerged after an initial exploration of the Sound Cubes. For example, one child (See Excerpt 5) started by exploring the different aspects of the Sound Cubes. She poked the screen, tilted them a few different ways and then connected them together and discovered that a melody was emitted when she gripped the cubes that particular way. The child spent the first minutes of her play tinkering and exploring the cubes, which are typical traits of the Explorer [8]. After discovering the specific motion that would emit a melody, she started swaying the cubes back and forth repeatedly and dancing in her seat to the melody emitted. By exploration the child found a trait of the Sound Cubes that was most appealing to her and used that in her play. That is a typical trait of the Improviser [8].
**Play Grid – The Explorer**

A majority of the children in this study may be seen as *Explorers* [8], partially because of the young age and their natural way of explorative interaction [10]. Their play consisted of them tinkering with the Sound Cubes hands-on, by trying to open the cubes, poking the screen or manipulating them in different ways to explore the different types of feedback. Such actions relate back to *sensory play* [13], because the majority of the play relied on the feel, sound and look [13] of the Sound Cubes objects. Examples of different types of explorations where the children investigated different aspects of the prototypes can be seen in Excerpt 8.

**Excerpt 8: Exploring the Sound Cubes in different ways**

Sequence 1: [Starts knocking on the cubes]

Sequence 2: [Poking the LED-screen display]

Sequence 3: [Looking at the LED-screen display]

**DISCUSSION**

**Open-ended play**

Since the Sound Cubes were only prototypes, they had a few properties that should be improved (e.g., opening of the cubes should not be possible for users). This needs to be kept in mind since designs that function best in the context of open-ended play are finished designs that can be played with but not modified [17].

Nonetheless, the prototypes were shown to work in the context of open-ended play. Their traditional block-like design and multimodality made it easy for every child to explore the prototypes in their own way and thereafter integrate their own interpretation of the objects into their play. This created many interesting and engaging interactions for the children.

A play object designed for open-ended play should not consist of any predefined game rules to enhance openness and endedness, while simultaneously providing the user with specific interaction rules. [17]. However, some of the children (3 out of 8) seemed at times bored with the design because of its simplicity and open-endedness, while the other children found it engaging and as a mean to create their own games and interaction rules.

The specific interaction rules of the Sound Cubes were for instance the shaking that lead to changing of figures, which showed to be too complex for the users’ understanding. This refers back to De Valk’s point of how designing for open-ended play is a battle between finding the balance between openness and complexity. Adjusting the aspects of ambiguity in output and pre-defined functionalities is key [6], and should be applied in further development of the Sound Cubes.

**Multimodal Feedback and Multisensory Stimuli**

The most interesting findings of this study are how the multimodal feedback and multisensory stimuli created opportunities for several different engaging interactions and manipulations of the prototypes that might not have been predicted beforehand. Therefore, also being great tools when designing for open-ended play. Furthermore, the interactions that emerged became very individual, personal, and subjective.

The multimodal feedback and multisensory stimuli had a positive affect on children’s engagement in the play. Some children (2 out of 8) chose to explore and engage in one interaction for a longer period of time, while others tried to explore every several aspects of the feedbacks provided, switching between different types of manipulations. This meant that one child could go from engaging in play where their goal was to emit a melody and then proceed to disregard the sound feedback and focus mainly on physical manipulation by, for example, trying to open up the cubes or stacking them on top of each other. The multisensory stimuli created perfect opportunities for *sensory play* [13], where the children’s visual, auditory and haptic senses were stimulated. And the combination of physical manipulation and multimodal feedback lead to the rise of *challenge play* [13].

The insights from the study show toddlers that usually fall into the play types of *Explorers* or *Improvisers* [8]. It can also be seen how multimodal feedback and multisensory stimuli can support the play of such play types. For example, being able to physically manipulate the play objects in order to receive different kinds of feedback leaves room for exploration. The *Explorers* have an opportunity to investigate several different aspects and thereafter adjust those aspects according to their preferences [8]. Similarly, the use of multimodal feedback provided *Improvisers* with elements that were appealing to them and that they could combine and integrate into their play whilst following their own rules [8].

However, when using multimodal feedback, it is important not to overwhelm the user. Notably, toddlers have a hard time focusing on several different aspects at once. This can be seen in the example mentioned earlier (See under heading “Digitally mediated actions”) where the Sound Cubes provided children with a digitally mediated action where by physical manipulation (shaking) they could navigate the LED-screen (digital). This functionality was not fully embraced by the users. This can be partially because of the earlier findings of how toddlers’ ability to understand physically manipulated digital representations is lacking. Another point can be a fault in the design, where the multimodality of the objects becomes overwhelming.
Design implications
Through the research study conducted and analysis of the data, several insights were gained. These insights and design implications could be kept in mind when designing similar objects for toddlers’ play experiences, and thereby be further explored.

Firstly, provide the user with simple physical manipulations and opportunities for tinkering – it is important since toddlers are to great extent explorers who rely on their motor skills. Secondly, when using multimodal feedback and multisensory stimuli in your design, think about not overwhelming the user. Toddlers usually focus on one or two of the modalities provided for them. Third, toddlers prefer individual play. Instead of striving to design something supporting team play, strive to design something that can create natural social interactions. Fifth, it is widely known that toddlers develop by playing. Therefore, the design does not have to support development or learning in any particular way. It is enough if the design can instead encourage engaging play and create meaningful experiences, consequently leading to children’s natural development. Lastly, using multimodal feedback can create motivation for behaviors, which children can then integrate into their play. This can make the play experience more personal and subjective.

Hedonic interaction and toddlers
Many pioneering educators such as Froebel, Montessori and Steiner believed in children being naturally self-motivating. Although not all educators believed in play and toys, reviewing literature about children’s play confirms that play is directly connected to children’s natural development [18]. This is why hedonic interaction, where the design’s goal is to create fun and pleasurable experiences, is something that is worth exploring when designing for children. This is even more applicable to toddlers who explore the world by playing. But since every toddler is unique, with a personal set of skills, needs, behaviors, and preferences the interactions designed should be flexible and open [10]. It is in this space that open-ended play designs fall into and can lead to interesting hedonic interactions and experiences for toddlers, which can also be seen in the results of this study. For example, the melody provided created an interaction where a child started dancing to it in their seat or when a child created a game of rotating the cubes against the table, thereby receiving sound feedback. The two examples mentioned could be viewed as hedonic experiences that emerged through children’s own interpretations of the Sound Cubes’ multimodal functionalities. Designing meaningful and fun experiences for toddlers is something that should be further explored within the field of HCI.

CONCLUSION
The aim of this study was to explore how the integration of multimodal feedback and multisensory stimuli in tangible objects can affect toddlers’ play, behaviors, and engagement in the context of open-ended play. During this research, two interactive prototypes called Sound Cubes were developed and an interaction study was conducted at a preschool in Stockholm. The results of this study give an indication on how multimodal feedback and multisensory stimuli can be used when designing open-ended play objects and how those can affect different play forms and play types. This paper also outlines important insights and design implications that designers could have in mind when developing interactive tangibles for toddlers’ hedonic interactions and play experiences.

FUTURE RESEARCH
Studying children and their interactions with technology is a complex research field with many subtopics. However, during this research study I found that toddlers are an understudied group within the HCI. Moreover, the research involving toddlers is often linked to designing products that are supposed to support their development or learning in some way. I would urge to shift the focus of some of the research to designing new and interesting experiences for toddlers’ hedonic interactions and play. As this study is not fully conclusive, more studies should be conducted where the goal is to create meaningful experiences for toddlers in the field of hedonic interaction and tangible design.

ACKNOWLEDGMENTS
I would like to thank the preschool for letting me carry out my study at their workplace as well as the children participating. I would also like to thank Martin Jonsson for his support and guidance during the writing of this paper.

REFERENCES


