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Designing a sonic interactive open- ended playground installation

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open-ended playground installation

*En soniskt interaktiv
lekplatsinstallationsdesign för fri lek*

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Abstract

The application of digital elements to traditional playgrounds can enhance children's outdoor play and counteract the growing trend of sedentary activities. This work reports the implementation and evaluation of a playground installation which looks at sound as the modality that can provide new and engaging play experiences. The design of this system follows an open-ended approach that let the children create their own emerging game goals and rules. The sound design is first tested in a lab setting and later on in a Swedish preschool, with a particular focus on the stages of play (invitation, exploration, and immersion). 38 children between 2 and 6 years old participated in a field study that lasted for three days. Children's engagement over time was quantified and field notes were taken during the whole evaluation. None of the children between 2 and 3 years old reached the immersion stage. On the other hand, children between 4 and 6 years old created their own rules showing parallel and collaborative play and, in some occasions, solitary play. The sound modality chosen proved to be effective to encourage children's play in a first place. In a longer engagement perspective, the soundscape partly supported an immersive play. The selection of the sounds to be integrated in the system demonstrated to be as fundamental as the physical appearance of the playground installation. The results of this study show how the visual and auditory modalities can be effective in an open-ended interactive playground and report the limitations of this design.

Sammanfattning

Additionen av digitala element till traditionella lekplatser kan förstärka barns utomhuslek och motverka den växande trenden av stillasittande aktiviteter. Detta arbete beskriver genomförandet och utvärderingen av en lekplatsinstallation med ljud i fokus som den modalitet som kan tillhandahålla nya och engagerande lekupplevelser. Utformningen av denna lekplatsinstallation skedde ur ett fri lek-perspektiv där barn skapar egna mål och regler till sin lek. Ljuddesignen är först testad i en laboratoriemiljö och senare i en svensk förskola, med särskilt fokus på lekfaserna (invit-fasen, utforskande-fasen och uppslukad-fasen). 38 barn mellan 2 och 6 år deltog i en fältstudie som varade i tre dagar. Barns engagemang över tid kvantifierades och noteringar togs under hela utvärderingen. Inga av barnen mellan 2 och 3 år nådde uppslukad-fasen. Å andra sidan skapade barn mellan 4 och 6 år egna regler som visar på parallell och samspelslek och i några fall ensamlek. Den valda ljudmodaliteten visade sig vara effektiv för att uppmuntra barns lek till en början. På längre sikt understödde ljudlandskapet delvis lek av uppslukad karaktär. Valet av ljud integrerat i systemet visade sig vara lika fundamental som den fysiska uppenbarelsen av lekplatsinstallationen. Resultaten av denna studie visar hur de visuella och auditoriska modaliteterna effektivt kan vara designade i en interaktiv lekplats för öppen lek, och begränsningarna av denna design rapporteras.

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ABSTRACT

The application of digital elements to traditional playgrounds can enhance children's outdoor play and counteract the growing trend of sedentary activities. This work reports the implementation and evaluation of a playground installation which looks at sound as the modality that can provide new and engaging play experiences. The design of this system follows an open-ended approach that let the children create their own emerging game goals and rules. The sound design is first tested in a lab setting and later on in a Swedish preschool, with a particular focus on the stages of play (invitation, exploration, and immersion). 38 children between 2 and 6 years old participated in a field study that lasted for three days. Children's engagement over time was quantified and field notes were taken during the whole evaluation. None of the children between 2 and 3 years old reached the immersion stage. On the other hand, children between 4 and 6 years old created their own rules showing parallel and collaborative play and, in some occasions, solitary play. The sound modality chosen proved to be effective to encourage children's play in a first place. In a longer engagement perspective, the soundscape partly supported an immersive play. The selection of the sounds to be integrated in the system demonstrated to be as fundamental as the physical appearance of the playground installation. The results of this study show how the visual and auditory modalities can be effective in an open-ended interactive playground and report the limitations of this design.

Author Keywords

Open-ended play, Stages of play, Interactive playground, Children, Sonic interaction.

INTRODUCTION

Literature has shown that play among young children is an important mediator in their physical, social, cognitive, and language development [1, 2]. In addition, access to an outdoor environment where natural elements are present has proved to play an important role in children's growth: fostering children's imagination [3] and leading to an increase in confidence, independence and development of motor skills [4]. In addition, playgrounds designed in a natural setting promote children's bond with the outdoor world [5].

However, a consolidation of hectic lifestyles together with an increase in screen time activities, have significantly

influenced the time children are spending outdoor, replacing outdoor play with largely sedentary activities [6,7].

Playgrounds that enhance their play with digital aspects could potentially counteract this trend and encourage children to play outside more. Such systems are defined as interactive playgrounds, combining traditional play with digital elements. The introduction of technology into playgrounds can enrich existing rules and provide new and engaging experiences. Tangible elements or embedded technologies can support interaction between people [8], promoting a more enjoyable and engaging play experience than that with screen-based activities [9]. Nonetheless, not every intervention is as successful or engaging [10] and researchers have been long focusing on design principles that can make interactive playgrounds more appealing. In the following sections, some of the principles that shaped the work of the current project are reported.

The stages of play

The integration of digital elements into traditional playground introduces new design challenges for providing novel play opportunities. The model proposed by De Valk et al. [11], presents a tool to guide the design process of an interactive playground towards playful experiences. This model was further developed with a focus on physical and social interaction [12] examining how interaction changes over time and goes through three stages: *invitation*, *exploration* and *immersion*.

The user experience starts with an *invitation* to play and it is triggered by multimodal components such as visual, auditory, and tactile information. At first, interactive qualities and affordances attract potential players to the design. Perceived affordances [13] communicate the opportunities and purposes for interaction and together with curiosity they drive the audience to the play. When children begin to explore and discover the possible design interactions, they move towards the *exploration stage*. Immediate feedback should then let the users understand what they can do with the system and how it responds to their actions.

By creating a game context, children continue to the *immersion stage* when they ascribe meaning to the interaction opportunities. At this point, they start to negotiate about rules, goals and games.

With a particular focus on the three stages of play just introduced [11], the present paper explores the use of sound

in a playground setting and how it could enhance children's outdoor play. The uniqueness of each place shapes users' interactions [14], thus the way environmental features support and affect children physical presence and play is investigated in order to fully comprehend how the design solution has to be embedded into the space.

With this in mind, lab settings clearly affected findings of previous works regardless the solutions proposed. In the stages of play model [11], the play sessions held in a lab compromised a clear distinction between the invitation and the exploration stages. Since users' initial engagement cannot be taken for granted, designing for invitation is fundamental. Users need to understand that there is a possibility to join in, whereas a lab setting itself already anticipate this first phase. Children are usually told beforehand about the test that they will participate, raising expectations and undermining the voluntary play which is one of the core aspects of the invitation stage. A more natural outdoor setting where children are free to play with various installations is expected to differently affect their engagement even if the novelty effect is still there.

Although researchers often considered their designs for a long-term engagement, they rarely tested the effectiveness over a long time-span. This particular study followed an iterative design process and assessed the varied solutions first in a lab setting and subsequently in a kindergarten for three consecutive days.

RELATED WORK

Literature offers a significant amount of heuristics for computer games and pervasive games as well as for traditional playgrounds [15, 16, 17] that can serve as a reference point for the design of interactive playgrounds. They combine elements of the explicit goals of computer games and the play opportunities of traditional playgrounds. Sturm et al. [18] propose a set of heuristics, identifying key issues related to the design of playground which incorporate sensors and actuators to actively encourage children to play: *social interaction, simplicity, challenge, goals, and feedback*.

Social interaction. Interactive play stimulates social interaction as well as physical play [9]. The range of games that children can define and the properties of the play objects (e.g. personal or shared) influence the type of social interaction. Designing for multiple users, for instance, support collaborative and/or competitive play, leading to specific design considerations like the division of roles or negotiation of common goals.

Simplicity. Children need to quickly understand how they can interact with the design otherwise their play would be compromised. However, simplicity does not necessarily imply that the game will be too easy, it can still provide hours or even days of challenge [17].

Challenge. Challenge is an element that recur in most of the design guidelines for games [15, 17, 19] and is described as the factor that gives excitement about playing a game. In the context of interactive playground, it can offer physical, social and cognitive challenges and it should be able to adapt to the

situation and the players. An appropriate design of challenges should consider the physical and cognitive skills of the target group, finding a good balance between tasks that can turn out to be either too easy or too difficult.

As children's cognitive and physical abilities change with age, designing for this target group needs to consider the different stages that define their growth. Although, research recognises that children grow differently [20], there is a general characterization introduced by the psychologist Jean Piaget [21] which frames children's development in a series of stages:

- *Sensorimotor.* This initial stage sees children's cognitions highly dependent on what their senses immediately perceive from their birth to the age of 2.

- *Preoperational.* From ages 2 to 7, children begin to think symbolically and to use words and pictures to represent objects. However, their attention spans are brief and still not fully capable of abstractions.

- *Concrete Operational.* From ages 7 to 11, in children appears the logical thinking about concrete events being able to assemble schema and consciously save them for reference.

- *Formal Operational.* From 11 years to adulthood, children develop the logical thinking and abstract reasoning they will use for their entire life.

In order to provide an appropriate challenge component, not only the 4 stages proposed by Piaget affects the design of a playground but also children's ability of improving their performances throughout their play.

Goals. To make the game appealing and motivating it is important to provide goals. The interaction opportunities can provide either fixed goals or emergent goals that users can create for themselves. This aspect gives floor to the open-ended play concept, further described in the coming section.

Feedback. Having a goal alone is not enough to create a challenging scenario. Feedback is required to let the user check whether the input has been received and the system is still working. This is also reported in Norman's interaction cycle where the system needs to show to the user the progress made [13]. There are different ways feedback may be given and diverse modalities can play an important role to the appeal of the game and the diversity of play that children can create [22]. The coming sections will further analyse how these modalities can influence children's play.

Overall, the elements above listed present a set of principles to take into account whenever integrating technology into traditional playgrounds. Sturm et al. [18], considered an extensive number of works related to interactive playgrounds and children behaviours in such contexts.

Children change their play continually, in some situations the game has fixed rules and in some other children self-regulate their play development creating own rules and goals. In this latter direction, the last decade sees an increasing number of projects with a focus on design solutions that support open-ended play.

Open-ended play

Open-ended play let the children create their own (emerging) game goals, by providing a design with several play

opportunities [23]. With relatively simple behaviours and without predefined goals previous research has shown that children were able to adapt their games to increase the challenge [24].

Rijnbout et al. [25] investigated how to design interactive play environments for open-ended play that support richness in play. They refer to richness in play as a setting that changes in character, form and nature over time where adaptive mechanisms and appropriate feedback affect children's interaction. The authors proposed three types of rules that users develop in an open-ended play setting: *interaction opportunities*, *interpreted rules*, and *additional rules*.

The interactive objects included in a playground provide the *interaction opportunities* that shape the way the users explore how sensors and actuators act and the interactions possible [26]. Whenever engaged to the design solution, children create a mental model of the system reflecting their understanding of how it works and what it offers [27]. Their interpretation of the game play and the interaction opportunities is described as *interpreted rules*. Moreover, *additional rules* appear in an open-ended play setting, where children enrich their game by establishing new possible interactions. At this stage, fantasy play and game-building support children in the creation of rules that can be more or less related to the interpreted rules.

Overall, the development of rules for open-ended play cannot be entirely predicted and designers can only create a setting that supports the creation of children's play.

Previous installations

Open-ended play has been interpreted by many design researchers in different playground solutions.

The project interactive pathway [28] represents one of the first explorations of open-endedness. The installation consists of a series of pressure-sensitive mats attached to motors that are activated when a child walks through the pathway. Although the pathway offers a simple design, diverse play patterns were observed: active play, fantasy play, exploration play, and game-building.

The use of light feedback in ColorFlares [29] also created diverse games, with varying levels of difficulty. ColorFlares are cylinders emitting light at each end and the direct manipulation triggered different responses, by rolling it (changing color) and shaking it (flashing color).

Bekker et al. [23], presented Flash-Poles as a solution to be placed in a playground. The concept was first evaluated with dummy poles to find usability problems and results were used in the final design. Each pole has three colored rings that can be rotated and pressed. Whenever pressed or rotated a light turns on. Pressing the ring determines the color of the light while the rotation set a timer according to the ring's rotation. The authors' goal of initiating physical exercise while being socially active proved to be successful in their installation.

FlowSteps [11] is another example of an open-ended play environment. The prototype developed consists of six interactive mats that contain a pressure sensor and six LEDs.

In the evaluation of the design, the three stages of play before mentioned were explored. GlowSteps [30] is an improved version of FlowSteps with wireless and more robust mats. Other solutions previously developed such as Morel [31], LedBall [18], Pinball Football, Virtual Basketball [32], and FeetUp [33] also represent an extensive work considered in the definition of the open-ended play.

Each of the interactive objects or playgrounds above reported use visual feedback as the only output modality. Rarely, auditory and tactile feedback are integrated in interactive playgrounds. Hompa, Bekker & Sturm [34] investigated how the use of diverse output modalities might affect open-ended play with interactive toys. Focusing on children interaction, the researchers compared a unimodal version of the object with the multimodal variant. Despite children were equally positive in both conditions, the study showed that using multiple output led to richer games, by assigning meaning to the three types of output adopted.

The selection of an optimal modality or combination of modalities should consider their specific characteristics [35] and how they would be perceived by the users. The feedback generated by the system should make users aware of what modalities are possible for their interaction, without getting them distracted from the task. The use of different modalities can increase the robustness of the interaction by presenting complementary information. However, designers should consider what modality suits better for the type of information that needs to be conveyed. Moreover, the modalities chosen should contemplate users' needs and abilities without ignoring the physical environment where they would be used [35].

Recently, by means of technology, there is an attempt to shift the perspective of sound design from reception-based approaches towards performance-based approaches. Seeking a more explorative engagement of the user with and within its surroundings, the goal is to design sound for action [36, 37]. Researchers also started to introduce the sound modality in the design of interactive playgrounds.

The DigiWall [38] soundscape takes advantage of both visual and sound cues to establish different types of interaction models: competition, collaboration and aesthetic experiences. Sound provides most of the necessary information to play with a digital wall equipped with climbing grips that react to touch.

Towards a more open-ended play, Jogo [39] introduces the use of tangibles and sensory feedback to stimulate both physical and social interaction. On the play surface, children can position balls of five different colours representing different notes. The position and the colour determine the sound generated by the system, used as a form of sensory motivational feedback. Jogo has proven to be successful for short-term play, however it was not evaluated in different contexts and over a longer period of time.

Sound has also been related to body position, where children could manipulate the musical parameters by means of specific movements [40, 41]. Beside incorporating toy

instruments in playgrounds, little research has focused on the use of sound in outdoor playground. In the work of Back et al. [42] sound feedback provided by a tube installation and communication nodes invited children to play in a natural setting, creating many different interaction patterns. The digital component integrated in this playground solution proved to stimulate children's play and influenced diverse play scenarios. In another work, Clair & Leitman [43] designed the PlaySoundGround that produces musical sound when children play on and with the equipment. The musical mapping of the play structures allows participants to explore different musical interactions. The user can alter the sound feedback, producing different music effects depending on the way the play structures are utilised. No specific results and findings are reported since the researchers did not carry out an extensive evaluation of the playground designed.

Considering the work done on musical playgrounds and the focus on sound as a medium for interaction, there are several advantages of using it in response to physical movements that can be valuable for the work of this thesis [44]. In contrast to visual feedback, sound is omnidirectional and doesn't require the user's directed attention. Thus, giving the possibility to the user of moving around the installation freely while receiving the information. Like visual cues, sound can provide information about physical events and directly affect user's action. Its different properties, such as pitch, loudness, timbre, and texture can be used to engage or disengage users.

The theoretical framework and the literature examined, serve as a reference point in the attempt to investigate and answer to the following research question:

How does the proposed sound design affect children's stages of play (invitation, exploration and immersion) in a natural play environment?

DESIGN PROCESS

In this section, the design approach adopted is outlined providing a complete overview of the different stages that defined the final solution since its first conceptualisation. The theoretical framework reported, contributed to the progress of the solution implemented that was evaluated in two iterations.

The iterative design includes the core aspects of a comprehensive evaluation and is grounded in an understanding of usability problems [45]. Testing the prototype uncovered usability problems and gave insights into children's different ways of interacting with the system. The initial concept was first tested in a lab setting, with an attempt to look at perceived affordances, interaction opportunities and game rules defined by children. In open-ended play, games rules and goals cannot be delineated beforehand, and that introduces a challenge in the design approach. The design should consider a balance between structure and spontaneity, making sure that the solution adopted is specific and easy to understand and at the same time general enough to encourage imagination [46].

At a second stage, the installation was placed in a natural outdoor environment and evaluated again with the improvements integrated after the first test. Results and findings are described more in details at the end of this report. Since the early conceptualisation of the installation, sound has been considered as the main element to be integrated in the interactive playground.

Sound interaction

To begin with, the goal of the present work is to create an interactive sound installation capable of entertaining and engaging children with no particular musical skills. The design offers the users the possibility to manipulate various sound samples in real time in a way that attempts to support collaborative play. Moreover, open-ended play opens up to different types of play that can be developed while interacting with the system. The sonic manipulation promotes active play among participants, where the use of sound is not merely meant to provide feedback but it becomes the essence of the possible interactions.

By means of physical actions, children directly affect different sound loops played by five nodes. The button placed on top of each node triggers distinctive sound loops locally stored. Moreover, sound loops are structured in sound layers. Whenever the system detects the same number of button presses at each node, the instrumental tracks of the five nodes shapes the musical texture of a polyphony, with indeterminate rhythmic intervals between the various instrumental loops.

The alteration of the sounds can be achieved by the top part of the pole which acts as a two-axis joystick (see Figure 1).

In the design just described, there is an attempt to look at sound interaction as a dynamic structure where music is no longer considered a linear composition. The use of sensors introduces a less apparent distinction between composer, performer, and audience. Even though input-output relations of the interactive system have already been designated, the interaction rules defined leave room to various game rules that can be established during the actual play [46]. These play opportunities, typical of an open-ended approach, let the children come up with their emerging rules and goals.

Does the sound element provide a richer interaction with the system and to what extent is it understood by the users? The evaluations will try to identify strengths and weaknesses of such design in the proposed system. Overall, sound serves as the main modality in the playground installation. However, visual clues are also contemplated to provide feedback and enrich the play.

The visual modality

LED strips are placed around each button and represent the second modality in use in this project. Researchers have reported how multiple modalities can support richness in play and the robustness of the information to be conveyed [34]. With this in mind, the reason of integrating LEDs is twofold: invite users to play and provide them feedback throughout their entire interaction.

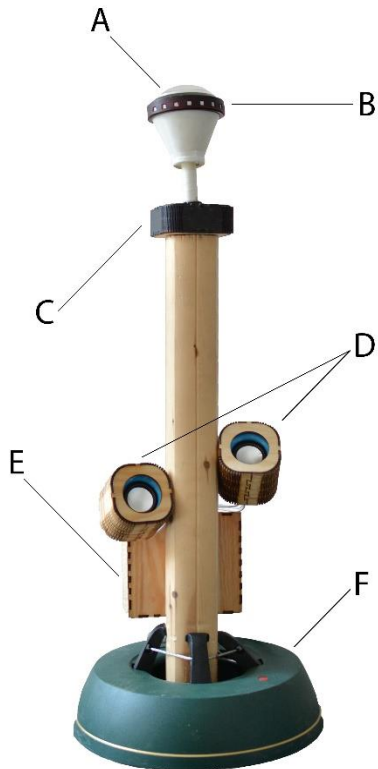


Figure 1. The interactive pole **a.** button **b.** LED strip **c.** wooden case housing the joystick **d.** speakers **e.** wooden box housing one Raspberry Pi and one power bank **f.** Christmas tree stand

As for the invitation stage of play, a “breathing” animation simulated by the LEDs attempts to draw children’s attention and evoke curiosity. Curiosity is a fundamental element in the world of game design [47] and in psychology is defined as one of the driving factors of human behaviour [48]. In the breathing animation, all the LEDs fades in and out simultaneously, in white colour, attempting to give the user the idea that the system is in a sleep-mode and ready to be activated. The *breathing status LED indicator* patent represents a well-known commercial example of a breathing effect indicating a sleep-mode status [49]. A typical way to awaken a device is to press any of its buttons. Similarly, the proximity of the LED strip and the button seeks to be a clear call to action, by inviting the child to further interact with the system.

At any moment of the interaction, the different LED animations being displayed show the state of the system. The *breathing* effect indicates the initial condition, where the sound loops are not activated. Whenever the button is pressed, the change in the LEDs animation shows the moment the system starts to play the different sounds. The LEDs displays a chase effect, where adjacent LEDs cycle on and off giving an illusion of the light moving along the LED strip. At each layer, different colours are used with the visual effect telling the user what sound layer is being played. On the sixth press, the node will loop back to the initial state and activate the *breathing* effect. These two simple LED states give the user a constant feedback on their progress. In

addition, their qualities might initiate various games rules depending on what meaning children ascribe to them. In this direction, the present work will investigate the value of the visual modality.

Do the visual clues invite children to play? Are the LED animations supporting and adding value to children’s play during the exploration and immersion stages? These questions will be considered during the test sessions and further analysed based on findings.

First evaluation

A first evaluation was held in a lab setting to elicit main issues related to the usability of the system. It proved to be helpful in order to gain insights on the interactions that appeared during the play session. Four children between 5 and 8 years old played with the installation for about twenty minutes without any specific restrictions. Parent’s consent was first asked through an informed consent form were general information of the study were given. The children were told beforehand that they could freely play with the installation and explore the possible interactions. In order to create a more spontaneous approach and not to bias their play or expectations, no additional information was given. The whole session was video recorded to make sure that minor details would be documented. In addition, observations were noted down about the aspects that represented the major critical issues. In the end, a short group discussion was carried out and some predefined questions were asked in an interview format.

Compared to the final design, this installation presented several differences in its appearance and the interaction rules designated. The system consisted of five nodes placed in a circular manner about 2 meters far away from each other. Changes in the x and y axes of the joystick were mapped to the pitch and volume of the sound file. Moving the joystick to the front and the back affected the pitch increasing or decreasing it, respectively. Tilting the joystick to the right or left altered the volume of the sound played. This feature gave the user the possibility of setting the volume off. Five distinct sound layers were designed with a total of twenty-five loops that could be played.

Findings from this evaluation session, reported some problems that occurred during children’s play. Overall, children never understood that sound loops of the same layer, indicated by the LED lights, would have created a more complex musical texture that they could have altered by tilting the joystick. Considering the three stages of play, users never reached the immersion stage. They kept on trying out the system without understanding its ultimate objective, thus being stuck in the exploration stage.

Although the LEDs were meant to guide the children through their play, having 25 sounds resulted in a too complex structure. It clearly appeared that the system didn’t follow the simplicity heuristic proposed by Sturm et al. [18]. Having the poles constantly playing the sounds that weren’t on the same layer, produced a confusing soundscape that hindered

a fluent play. On the other side, it was interesting to see that children came up with fictional rules that weren't part of the system. One participant thought the colours of the LEDs could be moved from one pole to the other by simply pressing the buttons.

In general, the goal of enhancing a collaborative play partially took place since participants were more focused on understanding the playground installation. When asked what children thought of the poles, they responded that they perceived them as music machines: *"It's a music machine, you press the button and music comes"*. As a whole, participants understood the more generic functionalities of the system expressed by the button and the joystick: *"You can set the music on and off and by moving it backward or forward you change the music"*. The change in the pitch was recognised as having a *"more calm"* or *"more energised"* sound. Children were engaged in the pitch alteration to the point where they were holding the joystick in position for 15-20 seconds. However, they were still doing it on their own in a more parallel play rather than collaborative. The social interaction expected was mostly missing, since no additional rules emerged during this session.

The observations made in this study, contributed to the improvements chosen for the final solution. It was clear that the whole design needed to be simplified and should have better invited for social interaction. It was necessary to alter some rules and feedback so that children would better understand that the poles depend on each other. Children need to explore the system to the point they recognise that they can play loops of distinctive sound layers which provide interesting musical results. This condition would help children to move towards the third stage of play which never appeared during this first test.

Final physical design

Looking at the final design, several design assumptions and findings from the test influenced the system appearance. Taking into account the goal of having children to actively alter the sounds, some ideas were first considered and then discarded.

At first, the button placed on top of the pole was intended to be the main controller of the system. Ideally, the user would have been able to select the sound layer and distort the sound output with the same component: the action of holding the button was thought as being a way to affect the music. However, this idea was abandoned because of the confusion and misinterpretation that it could have led.

It was then decided that for the sound manipulation it was needed a separate part from the button. Thus, a joystick was contemplated for detecting the user's intentions. At first, an analog joystick compatible with Arduino was tested and subsequently replaced with a bigger arcade version that proved to be more suitable for the final design. With regard to the button, two different types were tested in search for the best affordance. They differed in shape and

dimension. On the one hand the smaller button better resembled the shape of a joystick while on the other hand the bigger one provided a clearer invitation to press. The top-rounded shape and the dimension of the latter were crucial elements to convey the perceptual information of *'pressability'*. These last aspects were determinants for the decision of having the bigger button in the final design.

The actual realisation of the installation was made possible by using a laser cutter and a 3D printer. In order to adapt the arcade joystick to this solution, a 3D model printed in ABS filament was necessary to bind the button to the joystick shaft. In addition, a flexible 'belt' is stretched tight around the button's edge to make sure the LED strip is fixed in place. This piece is 3D printed with a particular flexible and strong filament called NINJAFLEX® (see Figure 2). Lastly, the parts housing the speakers, the hardware units, and the joystick's base are laser cut and screwed to the pole.

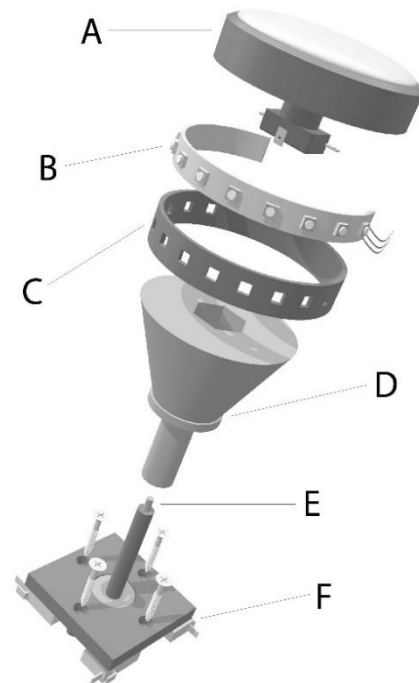


Figure 2. Exploded view of the top part of the pole **a.** Arcade button. **b.** LED strip. **c.** Flexible belt to hold the LED strip around the button. **d.** Support to bind joystick shaft to the top button. **e.** Joystick shaft movable in x and y axes. **f.** Joystick base screwed to the pole with 4 switch buttons to detect joystick's moves.

Final sound design

A new musical effect replaced the pitch and volume shift, attempting a clearer interaction. Changes in x and y axes were mapped to one singular tremolo effect, where the rapid reiteration of musical tones produces a tremulous distortion of the sound played.

In order to simplify the system, the number of sound layers was lowered from 5 to 3, by having 15 instrumental loops in total. The loops assigned to each node vary in duration and

instrumentation and are downloaded from online platforms where free royalty music loops are shared¹².

The three sound layers considered in the final design are all structured in terms of an evolutionary cycle and differ in their musical textures as following:

- the first sound layer combines vocal tracks (male and female choirs) with synth pads effects
- the second layer is a composition of five loops focused on a C pentatonic tonality (harp, voice, marimba, brass chords and drums)
- the third layer includes atmospheric sounds together with instrumental sounds (voice and viola) that evolve in a sparser and denser musical texture.

The sound choices of the three levels abovementioned made sure that, no matter in what phase relation, sound loops of the same layer would always result in a musical composition that doesn't need to be synchronized.

With regard to the visual feedback, the three sound layers were identified by green, blue, and red LED "chasing" animations.

Technical implementation

For a generic overview of the system, the installation consists of five nodes placed in a circular manner about 3 meters away from each other. Every node is a replica of the others and there is no communication between them. For this reason, one single node/pole is described in the following paragraphs. The only aspect that distinguishes each pole is the sound samples locally stored.

A node houses a Raspberry Pi 3 that allows the system to process the input data and to generate an output accordingly. Everything related to the auditory dimension is made possible by Pure Data (Pd)³, which is an open source software able to process and generate sound. The Raspberry Pi runs a python script which continuously communicates to a Pure Data patch.

In the Pd patch, three .wav sound files are written and stored in arrays and ready to be played and processed. According to the number of button presses, the patch triggers a specific sound and detects any alterations of the joystick. The one-way communication between the python script and Pure Data is made possible by the program, included in *puredata-utils*, *pdsend*. Whenever one of the 4 switch-buttons placed at the base of the joystick (see Figure 2) is pressed, it triggers a metro object in Pure Data which initiate a timer. The time the switch button is being pressed determines to what extent the sound is distorted. The timer is directly mapped to the distortion effect letting children manipulate the audio output in real time. The audio output is given by 2x3W speakers, USB powered. They are screwed to the pole facing upward to create the best audio configuration possible.

To display the visual animations, a strip with 12 WS2812 RGB LEDs is used. The LED strip is wired to the Raspberry Pi GPIO and powered by the 5V pin. In order to play the

LED animations, the python script detects the number of button presses and determines what animation and colour to display. The animations are taken and edited from the NeoPixels library.

Note that playing any sounds on the Raspberry Pi affects the control of the LEDs by giving a flickering effect. As a workaround, a USB sound card is plugged into the Pi and set as the audio output channel.

FINAL EVALUATION

The second and final evaluation was performed at the Tom Tits Experiment preschool located right next to its namesake Science Centre in Stockholm County. Its pedagogical activities are strongly bounded to the centre, where kids, if supervised, can access and experience the numerous installations regularly.

Their teaching approach attempts to foster children's creativity and their willingness to explore any material present at school. The kindergarten features a wide green area where kids spend most of their time when the weather conditions are good. Similar to an open-ended play approach, the school limits the presence of playground equipment that have pre-defined interaction rules such as swings, slides, toy vehicles etc. Instead, various materials and constructions give the children the possibility of creating their own emerging rules and games. Overall, the school attempts to give lots of time for free outdoor play. The teachers try not to simply supervise the children, their attitude is to provide a safe environment and to actively encourage children's own play.

METHOD

This section reports the quantitative and qualitative methods employed for the second evaluation carried out at the Tom Tits Experiment preschool. Findings from the final design contribute to the conclusion of this report.

Participants

In this field evaluation, 38 children participated at the preschool located in the Södertälje municipality in Sweden. Participants' age ranged between 2 and 6 years old. 38 out of the 62 kids enrolled at the kindergarten interacted at least once with the installation over the three days field evaluation. The rest of the children were not present at the school during the study.

Setup

The 5 interactive poles above-mentioned were positioned in a circular manner 3-4 meters away from each other, Figure 3 shows how the system was positioned. Speakers were facing inward to create the best audio setting in the play area. Each Raspberry Pi was powered by a 10000mAh power bank with a USB output port of 5V-2.1A.

In order to control and activate the installation, every Raspberry Pi(s) was wirelessly connected to an ASUS RT-N56U router positioned inside the school, approximately 15

¹ <https://www.looperman.com/>

² <https://freesound.org/>

³ <https://puredata.info/>

meters away from the system. A Lenovo y50-70 notebook placed indoors was also connected to the router where the VNC viewer software⁴ allowed to remotely control the five Raspberry Pi(s).

In order to determine to what extent participants engaged with the design, a logging function was coded. The python script running on the Raspberry Pi(s) recorded on a .txt file each time the buttons were pressed. Every Raspberry Pi registered the exact date and time the user pushed the button down.



Figure 3. The playground installation placed in the outdoor area of the school.

Procedure

Before the evaluation, an informed consent form was distributed to all the parents. General information about the evaluation and installation were provided and parents were informed that no pictures and videos were going to be taken. As in the first lab test, no information was given to children about the functioning of the system. They were told they could explore the installation freely and that they could spend unlimited time with it. The system was simply an extra game element during their free outdoor activities. At any time, children could stop and continue to play with some other games or vice versa. The installation was placed in a central area, where children would generally walk by or play. The system was positioned and activated at 13 o'clock of the first day and at 9am of the second and third day. Despite the lunch break and the indoor activities, the design was constantly running throughout the day until 5pm.

For the qualitative research, field notes were taken throughout the entire session. During the whole evaluation, descriptive and reflective information were noted down [50]. The researcher stood next to the installation without interfering with children's play during the whole test session. In order to facilitate the data collection, the field notes were guided by two major themes, the stages of play (invitation, exploration, immersion) and the different types of play (solitary, parallel, imitative, collaborative play). Whenever

any interaction took place between one or more participants and the system, the action was accurately noted down by reporting the time it occurred and its duration together with the number of children involved and their age. In addition, any comments or opinions given by the users were added to the descriptive information collected. Since the research was not a Swedish fluent speaker, the teachers helped with the translation of comments made by the participants. With regard to the reflective information, the teachers also gave precious explanations about children's behaviours and the overall school setting. Furthermore, there was an intention to recognise when and how children moved from one stage of play to the other. Throughout the whole evaluation, time was written down to better interpret the data collected by the logging files.

At the end of the evaluation, on the third day, a short group discussion was held where 6 predefined questions were asked to the children. This short interview was intended to elicit information about their general understanding of the system and about some of the games that emerged during the study. One teacher helped out during this session in order to mediate between the researcher and the large group of participants.

RESULTS

Field observations

All along the three days field evaluation, participants revealed two dominant behaviours: pressing the button and tilting the upper part of the pole. The top part of each pole proved to be the first element to be explored and activated. The sounds triggered by the buttons' presses encouraged every participant to further explore what the installation could offer. Since the first moment, children started tilting the top moving part of the pole. Some kids even started to argue about the poles' ownership and in a few occasions, this led to violent behaviours that had to be stopped.

Stages of play

Because of the informed consent form signed by the parents, all kids already knew of the system that was going to be tested. With regard to the invitation stage, children were attracted towards the design since the moment the installation was being set up. However, they were asked not to play with it until it was entirely assembled and launched. Nonetheless, some children started to play without permission showing strong curiosity towards the LEDs and the unusual shape of the posts.

As participants pressed the button and triggered the sounds, they moved forward to the *exploration* stage. Theoretically, children started to explore the new design since the moment it was being set up. Children asked numerous and persistent questions with the intention of understanding the functionalities and rules of the installation. However, practically speaking, users entered the second stage of play

⁴ <https://www.realvnc.com/en/>

when trying out different actions, seeking opportunities for interaction and play. In an explorative attitude, most of the children examined every single part of the poles. Some dedicated long time to figure out the source of the sound. At one point, when touching the front side of the speakers, one child shouted “*I can feel sound!*”.

The sound aspect was a totally new element in the playground area. As a result, children’s intention was to check out every sound the system could play. This entirely new experience engaged the participants for more than half an hour where the actions of pressing the buttons were all meant for the sake of playing the sounds and calling fellows’ attention whenever a new type of music was prompted.

In general, the *immersion* stage partially took place during the evaluation session. All children 2-3 years old and some older ones showed interest for a relatively short time during the first day without moving forward to a more immersive play. They stopped interacting with the system at the exploration stage and did not further engage with new games. However, different types of play occurred among some of the older participants. New games supported both parallel and collaborative play. At the same time, solitary play was still present where kids came up with individual games such as running through the poles to press as many buttons as possible or sequentially press the button and tilt the joysticks to alter the sounds of different posts.

Participants sporadically came back to play and joined ongoing games. Emerging games created by their peers facilitated their later engagement which would not otherwise had happened.

Age specific types of play

Among the participants emerged two distinct age groups that generally acted differently. Children between 2-3 years old showed only solitary or imitative play. They spent most of their time to explore the physical appearance of the posts. One kid in particular started to chase the light which was turning on and off along the LED strip by walking around the pole. Another child began to imitate his fellow’s behaviour with a different pole. Other kids, of the same age, kept on touching the installation motivated by the unusual shape. Many regularly put their fingers into the speakers’ boxes attracted by the music and the vibrations generated by the diaphragm. In general, this group of children interacted with the playground equipment for a short time that lasted around 5 to maximum 10 minutes in different moments of the first day.

Older children between 4 and 6 years old behaved quite differently. Their attitude was more inclined to a collaborative play and reported to be considerably longer in time than the younger group (up to 15-20 mins per game session), repeatedly along the three days. Running, dancing, singing, debating for game rules were behaviours that were typical for their play approach. These types of play were observed mostly during the second and third day, when children got familiar with the installation. Children’s

collaborative play never happened between more than 4-5 people at the same time.

A group of 5 children repeatedly danced around one specific pole. They either danced together by placing one hand on the button and turning around it or showed some dance moves separately. This practice happened at different moments in time but it was always one particular girl who was leading this game. She would try to draw her friends’ attention trying to get them closer to one pole. Because of children’s preference for the music being played in pole 2, it resulted the one played/used the most. Figure 4 reveals this predilection all along the three days, by reporting pole 2 as the one with the highest number of button presses. Participants specifically liked the drum loop played by the second sound layer of this node to the point that it also prompted the kids to sing. They generally improvised some singing for a few seconds that could match with the music played.

Children 4 to 6 years old did not only show collaborative play but also played individually in different manners. When pressing one or more button, children run through the installation with different goals in mind such as playing the sounds, setting off the same color animations, and pressing as many buttons as possible. At one point during the third day, one kid used a scoop to drop sand on the button. His intention was not fully clear and he then decided to leave the area. Another child used one stick to press the button: he repeatedly bashed it in order to activate the music.

Logging data

The logging feature implemented in each pole provided a more general overview of the users’ interactions. Note that this data only refers to the number of button presses over time, as shown in the graph reported in Figure 4.

Although the graph alone doesn’t provide any clear information about children’s enjoyment, it gives a generic picture about their engagement. With an explorative attitude, each participant tried out the new design in the first day of testing. The data recorded does not distinguish each user’s actions but the contribution of field notes documented that all 38 children purposively interacted with the installation. With the exception of pole 4 that reported technical problems, every pole registered a reduction in children’s activity as time passed, in particular in the second day. Over the last two days there is a steady drop in the children’s activity, showing a slightly higher interest at the beginning of each day and after the lunch breaks. Due to no activity between 12 and 13 o’clock, the data is not shown in the graph.

Interview results

From the questions asked at the end of the third day, the children’s understandings and opinions of the design implemented were pointed out. Participants had different opinions about what the poles resembled to them. However, these reports were all linked to something technological or

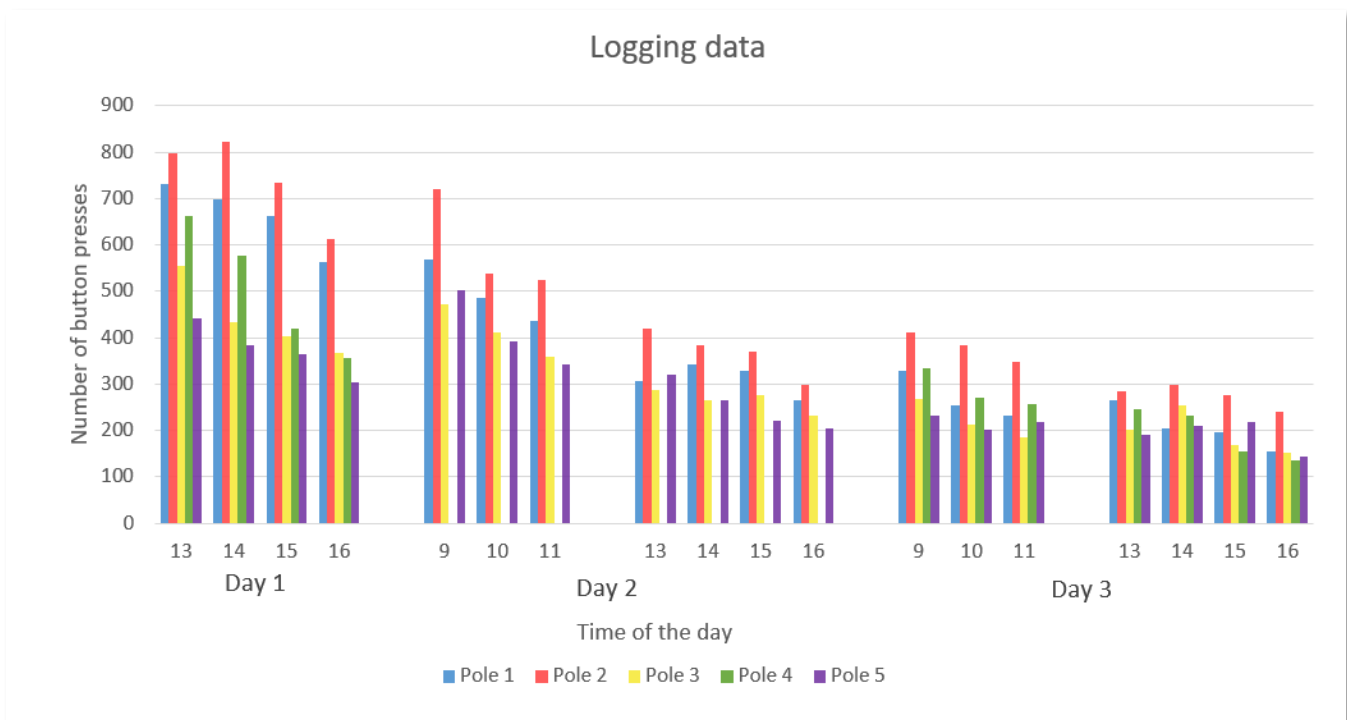


Figure 4. Logging data collected during the three days evaluation

musical. Someone claimed that the poles looked like big microphones or robots playing sound. A few others thought they were spaceships coming from the future. “*They look like they are not from this planet!*”, someone else added. When asked what music they liked the most out of the one played by the system was, they agreed that percussions were their favourite. A few other children mentioned that there were sounds somehow scary that they didn’t appreciate.

Children could remember the colours displayed by the LEDs but did not mention or hint at the differences in the sound layers. This result is coherent with the observational data in which no evidence was found of children playing games related to the sound layers. It rarely happened that all poles were playing at the same sound layer.

DISCUSSION

The following paragraphs will analyse and discuss the data collected indicating both expected and unexpected behaviours that occurred during the three days experiment.

To begin with, curiosity represented a critical element in order to drive users’ initial attention. In fact, the physical appearance of the system played an important role in this phase. Specifically, the LED breathing animation successfully drew children’s attention calling the participants for action. Their first approach turned into a clear intention to press the buttons. Thus, indicating that the affordance of the top part of each pole was prominent and well designed. With regard to the social interaction aspect, this stage was characterized by individual interactions where each child approached the poles by themselves. In two particular cases, children integrated natural elements

into their play. Although totally unexpected, a wooden stick and sand were used. In this context, the playground environment played an essential role and clearly affected children’s play opportunities. The presence of different materials afforded types of play that were not taken into account in the design process. These actions suggest reconsidering some aspects of a future design where natural materials can be part of the possible opportunities. Literature has also researched the potentiality of natural loose elements in children’s play behaviours [51]. Zamani & Moore [51] reported that these latter elements afforded constructive, dramatic and exploratory play behaviors whereas manufactured fixed elements mostly afforded only functional play.

The evidence that participants aged between 2 and 3 together with few older fellows never came across the immersion stage sets some questions to the current installation. From a designer perspective, looking at the heuristics suggested by Sturm et al. [18], it appears that the design fails to support emerging goals with these children. If curiosity and affordances encouraged their first interactions, these elements did not guarantee a longer commitment.

The sound modality

With regard to the movable part of the pole, children played with it during the whole evaluation period. First of all, selecting a bigger button and changing the musical effect to a tremolo effect proved to be more effective than the design of the first prototype. The musical effect was more effective for most sounds except for few sound samples where a tremble effect was already intended in the original files. In addition, the fact that children could move the “joystick” in

more directions supports the argument that movable parts are preferred to fixed elements. Many of the participants took advantage of the sturdy structure and kept on energetically turning the top part of each pole. This behaviour was not only related to the distortion of the sound output, the joystick bouncing back to its original position already represented a challenge and fun aspect.

Findings show that the sound modality, prompted by the button presses, fascinated and engaged the children in their first interactions with the installation. Yet, the designer challenge remained the user's long-term engagement with the system. From this perspective, the effect generated by the manipulation of the movable top part of each pole and the differences in the sound layers were expected to help children in the integration of goals and rules towards a more immersive play.

Children clearly stated and showed that they had their music preferences. On the one hand, percussions were the most appreciated and directly influenced their enthusiasm and their time spent with the system. On the other hand, the samples that were created based on atmospheric sounds or synth pads did not prove to positively affect children's play. Not only the physical appearance of the design determined children's satisfaction but also the sound samples chosen. Furthermore, observations made during the field study suggest that the sound modality played the most important role in getting the users to the immersion stage of play. Firstly, it proved to invite participants to explore the different sounds the system could play. The introduction of this modality in their ordinary play represented a novelty aspect in their playground arena. Secondly, the interaction opportunities of the design led to new games as reported before.

Limitations and future work

Based on the observations, some improvements could be done to enhance children's interaction with the system.

Despite the decrease in the number of sound layers and the attempt to create more distinct polyphonies, the final prototype was not fully understood by its users. The condition in which sounds of the same sonic layer were playing simultaneously rarely took place. This consideration leads to a twofold analysis as regards the sound design:

- the change in colour being displayed by the LED animations does not provide an explicit feedback that the sound layer is shifting. The system should give a more noticeable feedback that doesn't only rely on the LEDs. An alteration of the physical appearance of the pole might be considered as a viable way to convey the transition to a new sound layer.

- the sound layers should offer a greater difference to better distinguish the three diverse musical textures that can be created. In the current prototype, the musical files were locally stored on the Raspberry Pi, thus restricting the number of sounds that could be played. In order to provide a more variable play, a future version might consider a remote server, connected over the internet to the Pi(s), where numerous sounds are stored and periodically replaced. This

process would most probably affect children's play and the number of potential emerging games.

CONCLUSION

The field study conducted in the Swedish preschool focused on children's stages of play in the sound design proposed. Participants' curiosity and the system clear affordances played in favour of the invitation stage. Children moved forward the exploration stage when trying out the different features and interaction rules designed. Results of this test stressed that the playground installation designed cannot entertain for a long-term period the whole age range studied. None of the younger children between 2 and 3 years old reached the immersion stage. On the contrary, some participants, 4 to 6 years old, created their own rules showing parallel and collaborative play while running, dancing or singing. Nevertheless, for some of the older kids solitary play was still present during the immersion stage.

The playground environment affected children's play offering additional elements to be used with the system. In addition, the proximity of other playground equipment influenced participants' interaction by letting them choose between different outdoor activities.

The sound modality chosen proved to be effective to encourage children's play in a first place. In a longer engagement perspective, the soundscape partly supported an immersive play. The system requires a more appropriate feedback to communicate the change between the sound layers. Furthermore, the selection of the sounds should take into account children's music preferences and how they affect their mood and consequently their play. Overall, the proposed system and the visual and auditory modalities chosen turned out to be valid for an open-ended interactive playground installation. However, in an iterative design approach the sound aspect should be considered since an early stage of development. The selection of the sounds to be integrated in the system demonstrated to be as fundamental as the physical appearance of the final playground installation.

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