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CREATING DIGITAL MUSICAL INSTRUMENTS WITH AND FOR CHILDREN: INCLUDING VOCAL SKETCHING AS A METHOD FOR ENGAGING IN CODESIGN

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Abstract: *A class of master of science students and a group of preschool children codesigned new digital musical instruments based on workshop interviews involving vocal sketching, a method for imitating and portraying sounds. The aim of the study was to explore how the students and children would approach vocal sketching as one of several design methods. The children described musical instruments to the students using vocal sketching and other modalities (verbal, drawing, gestures). The resulting instruments built by the students were showcased at the Swedish Museum of Performing Arts in Stockholm. Although all the children tried vocal sketching during preparatory tasks, few employed the method during the workshop. However, the instruments seemed to meet the children's expectations. Consequently, even though the vocal sketching method alone provided few design directives in the given context, we suggest that vocal sketching, under favorable circumstances, can be an engaging component that complements other modalities in codesign involving children.*

Keywords: *vocal sketching, digital musical instruments, codesign, children, performance, prototype building.*

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INTRODUCTION

Applications of sound and music computing increasingly are becoming available to the general public, as demonstrated widely in both academic assets and commercial products. However, these tools largely capitalize on personalized content, from both user and provider perspectives (Mason, Jillings, Ma, Reiss, & Melchior, 2015; Riedmiller, Mehta, Tsingos, & Boon, 2015). For instance, streaming services for music have intricate recommendation systems (Song, Dixon, & Pearce, 2012), and connected playback devices adjust to users' relocation and surroundings (Francombe et al., 2017). Increasingly, end users also can change their sonic environments to their liking (Eriksson, Atienza, & Pareto, 2017). These tendencies toward personalization pose several challenges to design tasks focusing on music technology, one of them being how to allow end users to convey sonic preferences for the purpose of system design. One research method proposed in this context is *vocal sketching*, that is, to sketch sounds using one's vocal apparatus (Ekman & Rinott, 2010). Vocal sketching, along with verbal descriptions of nonvocal sounds, previously have proved effective in, for instance, recognition tasks (Lemaitre, Houix, Voisin, Misdariis, & Susini, 2016; Lemaitre & Rocchesso, 2014). In recent studies (e.g., Panariello, Sköld, Frid, & Bresin, 2019), researchers have approached aspects of communicating sound preferences using a vocal sketching methodology.

The purpose of this work is to explore whether vocal sketching techniques can be applied successfully in codesign situations with very young users who have no formal experience in expressing sounds for design purposes. Specifically, we set out to probe whether preschool children are capable of describing "fantasy musical instruments" with sufficient sonic detail for developing new digital musical instruments (DMIs) or new interfaces for musical expression (NIMEs). The study involves master of science (MSc) students' interactions with children in a codesign workshop environment. In this research design, we could collect valuable information from both the work process and the results, as well as observe how the vocal sketching contributed to the design as one of several possible design components.

The inclusion of children in design processes in technology- and engineering-based learning activities (Harriman, 2015) and elementary school pedagogy (Rosas, Behar, & Ferreira, 2016) is a growing trend. However, little research has been published on children as designers of DMIs or NIMEs. Early work in this field focused on expressive DMIs *for* children as a way of engaging in learning activities (see, e.g., Weinberg, 1999). Researchers have dedicated considerable energy and resources toward the design of instruments for novices. However, participatory design methods have not been so prominent (see, e.g., an overview of recent work in McPherson, Morreale, & Harrison, 2019). In a study by Mazzone, Iivari, Tikkanen, Read, and Beale (2010), three different design activities were carried out for the design of a musical device for children. The authors explored outcomes of the employed methods to understand the activities from two perspectives: whether the methods contributed to the design of a mobile music application and whether they suitably involved children in the process. They presented general considerations about conducting design sessions with children that can also be applied to other design contexts. Their findings suggested important design considerations: (a) involve teachers or education experts before and during the design sessions, (b) use props (and media) to initiate engagement by the children, (c) vary the communication channels using expressive tools (e.g., drawings, prototyping, acting, storytelling, or playing),

(d) record the progress and end results, and (e) allow experts from different disciplines to analyze the results.

In the study described in this paper, we invited 15 students enrolled in an MSc course on musical communication and music technology to codesign novel DMIs together with five preschool children. The students initially interviewed the children in a workshop after which they had 2 weeks to build the children's envisioned instruments. A central task given to the students was to engage the preschool children in vocal sketching to describe the sounds produced by their envisioned instrument. The produced instruments were showcased at the Swedish Museum of Performing Arts, where the children performed the specific instrument they helped design.

The pedagogical perspective of the study presented here is primarily concerning higher education learning—and not that of preschoolers. This perspective was reported in Hansen, Latupeirissa, Frid, and Lindetorp (2020). Below, we describe the perspectives of our study focusing on a codesign workshop employing participatory methods, in which DMI design was conducted with children as informants. The purpose of the described work was not to conduct a controlled experiment for assessing vocal sketching independently or to produce excellent DMIs; the aim communicated to the students was to explore instrument design methods. In essence, we were interested in exploring how the students could engage the children in using vocal sketching in a casual but inviting environment and whether the children could produce design instructions by imitating, imagining, and portraying sounds. To establish the context as casual and inviting, the students were instructed to allow for any method and means initiated by the children and in any modality (gestures, drawing, movement, verbal descriptions, among others).

Vocal Sketching

Vocal sketching involves the use of the voice and body to demonstrate the relationship between action and sonic feedback (Rocchesso, Serafin, & Rinott, 2004). The method of sketching sounds using the voice has grown as a field of audio research. Although researchers employ various definitions of the concept of vocal sketching, the method could be described simply as a counterpart of sketching by drawing on paper (Delle Monache, Rocchesso, Baldan, & Mauro, 2015), where the intended output is an imitation or demonstration of a nonvocal sound (Lemaitre et al., 2016). The term vocal sketching, coined by Bencina, Wilde, and Langley (2008) and presented in work by Ekman and Rinott (2010), was inspired by the notion of "vocal prototyping" for vocalized bodily movements in artistic performances or installations. It can be considered as a methodology for addressing sound design, alleviating the challenges inherent for nonexperts when thinking and communicating about sound in early design stages (Ekman & Rinott, 2010). Ekman and Rinott emphasized the importance of paying attention to social barriers to vocal interaction and ways to overcome obstacles such as shyness in a group setting when using vocal sketching. In their study, they included a warm-up task, a series of design tasks, and a concluding session for reviewing the results and share reflections on the process.

Vocal sketching can be effective particularly when describing sounds that do not have clearly agreed-upon symbols in language, for example, when the source of the sound cannot be identified or when communicating sound characteristics that are ambiguous, such as pitch or temporal qualities (Ekman & Rinott, 2010; Lemaitre, Dessain, Susini, & Aura, 2011). The European research project SkAT-VG (Sketching Audio Technologies using Vocalizations and

Gestures; Rocchesso, Lamaitre, Susini, Ternström, & Boussard, 2015), explored vocal sketching as a method for design and included the results in a sound design toolkit (Baldan, Delle Monache, & Rocchesso, 2017). The SkAT-VG project explored not only vocalization but also complementing gestures (Delle Monache et al., 2018). The project focused partly on sound classification and recognition from sketches and partly on design and synthesis. Vocal sketching as a method has been proved to be feasible, enjoyable, and applicable to design processes even without prior vocal training (Ekman & Rinott, 2010). However, little work in this domain has focused on how it can be used in early design processes with children, which is our focus in the current work.

Children as HCI Designers

Although numerous studies report on designing musical instruments *for* children, very few papers have addressed the topic of designing *with* children. Typically, studies involving musical instrument design target children older than the preschool age or children with special needs, and often also indicate a resolute constraint in technology, such as constructing with, for example, LEGOs. In an overview, Muller (2007) noted that some design approaches historically have been more common when working with children in the design loop. Nesset and Large (2004), for instance, described several design methods adopted for working with children: user-centered, participatory, contextual, and scenario-based. In user-centered design, the developer considers how the product is best adjusted to the user, while in participatory design (or codesign) the intended user is included throughout the design and development processes. In contextual design, on the other hand, developers aim to understand user needs, mainly through observation. Finally, scenario-based design presents a user situation as a fictitious story.

Another approach has been to investigate the four distinct roles a child can take on during design tasks: user, tester, informant, and partner (Druin, 2002). When the child acts as an informant, the design team can choose to include the child at various stages. When the child acts as a partner in design, the role is intentionally more active throughout the process: Ideas typically develop through a collaboration between adults and children. We treated the children primarily as informants, where they contributed with sketches, descriptions, and ideas at the beginning of the design process.

According to Druin (2002), working with children as informants can be done, appropriately, either in their school setting or in environments that support the project goals. Although many previous studies have focused on children aged 7–11 years, we applied similar concepts to younger children.

Research Questions

We did not anticipate that children would be able to envision completely new instruments; rather, we expected them to describe ideas based on previous experience. Thus, we investigated the agreement between the child's description of an instrument and the students' proposed DMI prototype through analysis of annotated recordings from the workshop and the presentation of the instruments. In particular, we looked for traits of how sound preferences were communicated (by the children) and realized (by the students) in order to answer the following questions:

- Can vocal sketching be used by young children to communicate their ideas of new musical instruments via sounds?
- How suitable is vocal sketching when it comes to engaging children as active participants in a design process?

METHODS

The study described in this paper took place at the Swedish Museum of Performing Arts in Stockholm. We followed the five guidelines suggested by Mazzone et al. (2010): (a) involve teachers in the study preparation, (b) engage children using props, (c) allow multimodal and expressive communication, (d) record the progress and end results, and (e) involve experts from other disciplines in the analysis.

Participants

A group of five children from a local preschool (3 F, 2 M, 54–77 months of age, all with good verbal skills), were invited to participate in the study. The children had previously taken part in experiments with sound in interaction at the same museum (Frid, Lindetorp, Hansen, Elblaus, & Bresin, 2019). They also had participated in two lessons at their preschool focusing on musical instruments. During the first session, the children tried about 50 musical instruments (primarily percussive, classical, traditional, and popular instruments, but no synthesizers or other DMIs). As a creative task, they also created a double-reed oboe-like instrument from a drinking straw. During the second session, they were introduced to amplification, synthesizers, and audio effects. The preschool involved in this project had no particular focus on music pedagogy; however, the children participated regularly in singing activities and a pianist visited them biweekly.

Procedure

We carried out the study within the framework of an MSc course on musical communication and music technology; to involve students is an attested approach in our research (Hansen et al., 2019). The task of the students was to develop DMIs for the children, as described in the previous section. Fifteen students prepared for the study through a range of activities. They participated in lectures on vocal sketching, sound synthesis, the role of sound quality in interaction, NIMEs and DMIs, and mapping of an instrument's control and sound parameters (Hunt & Kirk, 2000). Additionally, they received practical exercises and introductions to music programming in Pure Data (Puckette, 1997), sound design, and interface building using Bela boards (McPherson, 2017). From their study programs, most or all students previously completed courses involving participatory design methods. For this course, they planned a workshop focusing on designing musical instruments with the preschool children.

The children were not explicitly introduced to the concept of DMIs during the project. However, one week prior to the children's meeting the students, the preschool teacher started discussing traditional musical instruments with the children, and they were encouraged to draw "fantasy instruments" on paper. The day before the workshop, one of the authors demonstrated vocal sketching for the children at the preschool and engaged them in a playful activity of producing sounds vocally. In other words, vocal sketching was not presented as a design method. The exercise involved examples of both portraying the sounds of animals and musical instruments onomatopoeically and of imitating such sounds more realistically.

During the workshop at the museum that the 15 students organized as part of their course work, each child was paired with one representative from a group consisting of between two and four students. The workshop was organized in three steps, as follows.

Step one: The child–student pairs visited a museum exhibition called Sound Check. This exhibition presented 17 novel musical instruments that visitors were invited to try; many of these were DMIs. The presented interfaces ranged from interactive sonification of radiation to a pinball machine with repurposed bass guitars. The children observed and tested these musical instruments for 45 minutes. This activity was important in the workshop for two reasons: This session allowed the children to become familiar with their student-group representative and vice versa, while it also allowed the students and children to establish a common point of reference in terms of musical interfaces. Many of the creations presented at this exhibition demonstrated how various mapping strategies impacted how the instrument is experienced by the player, thus providing a basis for discussion and learning material for the students.

Step two: Following the introductory activity, the student-group representatives presented their child-informants with the task of envisioning and describing a fantasy musical instrument. However, they did not explicitly suggest that vocal sketching or any other method should be used by or with the children when they gathered information.

Step three: Each child–student pair completed an interview session. The students had prepared for their interview sessions based on guidelines for interviewing children (Cohen, Manion, & Morrison, 2002, p. 528). For the purpose of the study, students were encouraged prior to the workshop to conduct practice interviews with children from their social sphere, if possible. The students had been instructed to attempt to lead the discussion about musical instruments if the child would not express design ideas spontaneously, which is common for the partners in a design approach. Although the reference literature (e.g., Cohen et al., 2002) recommended conducting interviews with children in a familiar setting, we decided (in consultation with the preschool pedagogues) to carry out the interviews at the museum. The location was useful for practical reasons but also because we considered it worthwhile to bring the children to a novelty-inspiring environment and build trust through accompanied exhibition visits. All the interviews took place simultaneously in a workshop room set up at the museum. The room was equipped with one video camera and one Zoom HD4 Pro audio recorder per pair for recording and documentation. The entire session was scheduled to take approximately 30 minutes, but the groups were allowed to allocate more time if needed. The teacher and the parents waited by the open door to the room; they could decide to stay within or out of sight.

Design Process

To assist in the group work, we provided access to the children's videos and audio recordings through a nonpublic encrypted streaming service. The students designed the DMI for their respective child based only on the above-described workshop and interview session. In cases where the students needed technical support, for instance, with programming or hardware issues, a teaching assistant was available. The students built their interfaces in a well-equipped prototyping lab located at KTH Royal Institute of Technology. All DMIs were built using Bela boards, sensors (e.g., accelerometers, buttons, sliders, conductive fabric, piezo elements, proximity sensors), and external loudspeakers. Pure Data was the primary programming method. A significant design requirement imposed on the students, apart from following the guidelines defined by the children, was that the instrument should not involve any computer technology beyond the Bela (or a similar microcontroller) and should emit sound through embedded loudspeakers. Preferably, the DMIs should not depend on producing mechanical sounds or be made to resemble acoustic instruments. In addition, design decisions should be motivated by and considered in relation to the course literature and explicated in the form of a written project report that followed a conference proceedings paper template.

Although not specifically explained to the students, all the groups followed a scenario- and contextual-inspired design approach. In this approach, they needed to suggest a target solution quickly, grounded on a basic understanding of the child and his/her goals and presumed actions. Thus, the child acted mainly as an informant in this context and no user-centered techniques or participatory steps were applied in the development process. Instead, the students interpreted the child's description of the final product and added functionality to the design accordingly. Instrument development was completed without intervention from teachers or parents. With only 2 weeks for building the instruments, students had little time for prototype iterations.

Presentation and Showcasing the Instruments

The instruments were showcased at a performance event scheduled 2 weeks after the workshop. At this point, the children revisited the museum to demonstrate their respective instruments together with their student group. The children were provided 45 minutes to try out their instruments together with the students in an informal session (i.e., rehearsal). This period also allowed the children to demonstrate the instruments for each other. After rehearsal, the children and their parents revisited the museum exhibition and had a break. Then, an audience of around 30 persons—consisting mainly of the parents of the children, friends of the students, museum representatives, and colleagues of the authors—attended a public performance showcasing the new instruments. During this performance, each child was allotted several minutes to demonstrate his/her instrument. A microphone and small PA system were used to amplify the output from the instrument's loudspeaker. We video recorded the entire performance for subsequent analysis and documentation.

After the performance, the children and the audience were invited to try all the instruments in an open hands-on session. The researchers took the opportunity to collect informal feedback from the children's parents, the preschool teacher, and the audience members at this point. In total, the children played with their instrument for about 90 minutes, encompassing the rehearsal, presentation, and the concluding open session.

Analysis of Results

Two researchers from KTH, who were familiar with the sketching method but not yet involved in the study until this point, were invited to actively observe the public presentation and then watch, annotate, and analyze the recorded material from both the workshop and musical performances. Specifically, they were instructed to annotate instances of vocal sketching or other articulations of sound preferences, as well as descriptions of gestures or other design input provided by the children. In addition, they attentively observed how the children interacted with and appropriated the instruments. Following the steps of observation and annotating, the researchers compared their annotations from the workshop recordings with the instrument design as performed by the children in the concluding musical performance recordings. The goal of their analysis was to assess how vocal sketches and other information gathered in the workshops seemed to affect the instrument outcome. We include their insights along with our own within the Results section.

Compliance with Ethical Standards

The study did not involve any stressful procedures; thus, no ethics approval was required for the behavioral studies reported in this paper. We conducted the study in accord with the KTH Royal Institute of Technology's ethical policy. For the management of participants' personal data, we followed regulations supervised by KTH's Data Protection Officer. Parents of the preschool children were required to sign a consent form prior to their children's participation in the study. The informed consent included information about the study, the task, and the analysis. All parents and students consented to possible future publication of photo and video material from the experimental session. The participating teacher and all parents received a post-review version of this manuscript and have read and approved the information presented here.

RESULTS

Five new DMIs, as performed by five children, were included in the analysis from the workshop and presentation. Here we report on some general results from the workshop and DMI development before describing each instrument and the embodied experiences of the children performing with them. We also describe the role and impact of vocal sketching for the development of each instrument.

Interview Sessions and Workshop

All interviews were conducted as planned. Only one of the five children asked to have her parent with her; the rest of the children were alone with their student-group representatives during the interviews while the parents waited out of immediate sight. The teacher did not have to intervene to comfort or support the children. All the children were engaged in the conversation, so the noise level in the workshop room was quite high. Nevertheless, recorded sound and video material were of sufficient quality for annotation and analysis of interview dialogues. We note that the workshop session did not generate a large number of vocal sketches. As such, we found no need for a quantitative analysis based on high fidelity audio recordings.

The children used various methods for describing their imagined instruments, including verbal descriptions, playing techniques demonstrations and gestures, sketches and drawings on paper, as well as comparisons with existing instruments. They also used vocal sketching, vocalizations, and singing to a certain extent, and created sounds with the help of their body and nearby objects. Figure 1 shows an example from the workshop where the child described details in a drawing for the envisioned instrument. (The built instrument is presented in Figure 6). We had encouraged the students leading the workshop to allow for and engage in such multimodal activities. Some students

Figure 1. A child describing the pipes of her imagined pan flute-like instrument to the student through drawings during the workshop interview. The final version of the instrument is shown in Figure 6. The image is used with permission.

resorted to vocally sketching themselves in order to encourage the child to behave similarly. Other students gave examples or other suggestions to which the child could respond and react.

The limited number of vocal sketching recordings obtained from the workshop resulted in our decision not to consider quantitative audio analysis as worthwhile. Instead, we transcribed the video and audio recordings to extract the children's descriptions of their envisioned instrument, regardless of descriptive method or presence of vocal sketching. We report on the sound descriptions per respective DMI below.

Instrument Development

During the 2-week instrument development period, we recommended and facilitated that students create the DMIs using the Bela board hardware and the Pure Data software; other resources could be added, if needed. We also strongly encouraged the students to use Bela with batteries and an integrated loudspeaker in order to be able to create small and autonomous instruments. The primary expectation, however, was for each group to manufacture its child's described instrument as accurately as possible.

The instrument interface building took place in the campus prototyping lab that provided materials and technologies such as a laser cutter for wood, a soldering station, a sewing machine, and a 3D printer. Three interfaces were assembled from the ground up, while two were reengineered from existing toys (see, e.g., Figure 2). For the most part, the audio synthesis relied on playback and manipulation of sampled sounds using Pure Data. None of the project groups seemed to run into performance issues with either Pure Data or Bela. The main challenge appeared to be to obtain useful senor input in instrument design. All students were new to the Bela platform, but many had experience with Arduino, which has some commonalities.

Each DMI in its final configuration is presented below together with references to the child's original description, observations from the performance, excerpts from the transcribed material, and, when appropriate, additional insights from the written project reports completed by the students. We present the instruments in the order of youngest child (54 months) to oldest child (77 months).

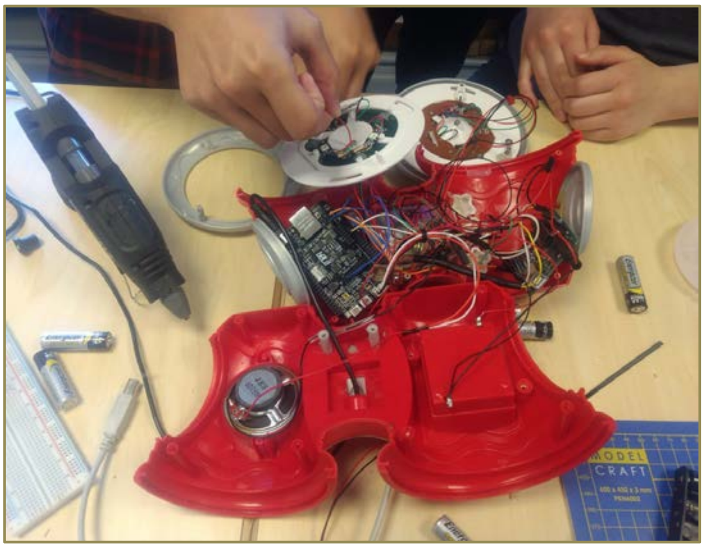

Figure 2. Students repurposing a toy drum for quick prototyping by adding a Bela board and sensors to construct the "Maja" drum (shown in Figure 5).

Instrument 1: "I Pour Soy in the Piano"—A Sushi Table Keyboard Instrument

The child did not use vocal sketching when describing this envisioned instrument; however, he described the sonic outcome of the instrument in detail using a narrative of the interaction with the instrument, which also explains the very explicit name. Interestingly, the proposed design of the envisioned instrument was clearly inspired by real experiences, thus reflecting the transformation of everyday experiences into design ideas, something previous researchers have mentioned as a challenge for children participating in codesign tasks (e.g., Vaajakallio, Lee, & Mattelmäki, 2009). The instrument was to consist of a piano-like keyboard that could be played in a traditional manner using the fingers. The boy described the keyboard layout in a drawing: The keys were supposed to have alternating sounds of eating sushi and, in his own words, of "*drinking soy sauce that is mixed with carbonated water*." The instrument should look like a piano (although the black keys were not included in the drawing), but it should not sound like one. One specific gestural control was demonstrated in the workshop: It involved pouring soy sauce into the piano keyboard. Moreover, the boy specified including a big button that could be triggered through a motion similar to "*a dog digging a hole in the ground*" (as demonstrated with a scratching gesture). A key feature of the instrument was that one should be able to eat while making music.

Much of the interview with this child focused on describing the physical characteristics of the instrument. Consequently, the visual representation corresponded well to the child's description. The final design of the instrument, shown in Figure 3, consisted of a low table intended for eating sushi as well as an integrated MIDI piano keyboard. (It would be venturesome to build a new keyboard without black keys.) As the descriptions of the sonic output were verbal rather than from vocal sketches, the students decided to use sampled sounds of pouring and chewing. Thus, the piano keys trigger various audio recordings of eating sushi and drinking soy.

The child had requested to be able to literally pour soy into the piano as a playing gesture. However, for a number of practical reasons, the students decided to adapt this feature to interaction with a soy bottle placed on the table. The bottle was situated on a pressure sensor that

Figure 3. Playing the keyboard interface of the "I pour soy in the piano" instrument. On the table is also a soy bottle on a pressure sensor and a rectangular cushion with hidden buttons for drumming; the other items on the table were props. The image is used with permission.

would, depending on the amount of soy left, control the playback and sound level of a Japanese-themed music soundtrack. The design instruction of pouring soy into the piano was thus abandoned, to the child's expressed disappointment, but the soy bottle feature was kept. A large padded cushion on the table surface with integrated buttons could be pressed to produce drum-like sound samples and was intended to support the suggested "a dog digging a hole in the ground" gesture.

The instrument was designed with the child's body in mind: The table size was adjusted so that a small person could reach it and play on the instrument from all directions. The design combines familiar experiences from both playing piano and passing a bottle of soy at a dinner table. Interestingly, the child attempted to explore the device's possibilities and limits in terms of embodied musical actions. For example, he sat on the floor to play all the keys simultaneously, using his arms. He also looked underneath the table to see if he could examine the technical construction. Interaction-wise, the keyboard was played using the fingers, but the interaction described as "pouring soy into the piano" and "digging like a dog" were approximated by the soy bottle's weight and hitting the cushion, respectively. In the students' written report, they described how they tackled the challenge of turning the unmusical and mundane eating-sound experience into a musical one. In particular, they explored the cartoonification methods developed in the Sounding Objects project (Rocchesso, Bresin, & Fernström, 2003).

Instrument 2: "Elsa"—A Unicorn Instrument

The child who described this instrument was rather shy and did not engage much during the interview. She used no vocal sketching or paper drawing, instead she asked immediately for a purple unicorn. The further descriptions that resulted from the interview were presented by the student as various options, such as "big or small," "high or low," "one or two buttons," and so on, from which the child chose. The child did not give any instructions regarding the instrument's sounds apart from wanting a "*unicorn sound*," but she described that it should make several different sounds, rather than just a single one. When asked how the instrument should be played, the child made a violin-bowing-like gesture. Back at the preschool later that day, the girl started on her own initiative to experiment in order to find sounds for her instrument, and she asked her teacher to call and tell the students that she wanted the unicorn to sound like *"shaking a pearl in a glass."* This was included in the design directives and was the only interaction between the students and children after the interview. According to the interview and this additional description, the instrument was interpreted to take the shape of a purple unicorn sitting on the ground, be about 30 cm tall, have multiple sounds, and one button.

The final instrument was a repurposed purple unicorn plush toy, shown in Figure 4. An accelerometer, a button, and a loudspeaker were held by the unicorn in a hugging fashion. When tilted, the instrument plays the sound of a glass pearl bouncing rhythmically in a glass container. However, the tilt is measured using the accelerometer and not from a bowing-like gesture. The sounds resemble a glockenspiel and were programmed to allow for playing melodies in three octaves. The button on the back plays a "unicorn sound" that was designed as a sparkling sound of several glass pearls bouncing more energetically in a glass container. According to the students' project report, they decided early on that having several sounds connected to the button would not be intuitive. To open up the design space, they added the accelerometer control for making it possible to produce melodies by tilting around two axes.

When trying out the instrument, the child held it in front of herself with her arms straight and then tilted it back and forth (see Figure 4a). She did not hug the instrument much, contrary to what children typically do with a soft stuffed animal. After receiving instructions from the students, she also tried tilting it sideways, as well as pushing the button (Figure 4b). The instrument design offered an interesting embodied musical experience where the child had to learn how to tilt the unicorn in order to control the pitch.

(a) (b)

Figure 4. Playing the Elsa instrument which consists of a unicorn plush toy equipped with an accelerometer, a loudspeaker, and a big button placed on its back. It plays pitched sounds similar to bouncing glass pearls when tilted. The images are used with permission.

Instrument 3: "Maja"—A Bongo Drum Set

This child used vocal sketching to some extent. Specifically, she produced the sound of a drum by saying "*boom*/*poom,*" and she sang the *Pippi Longstocking* theme song. Moreover, she specified that the drum should "*decide for itself*" what kind of music it should play, as well what it "*is saying.*" In addition, the drum should play the song "Let It Go" from the Disney movie *Frozen*. She indicated that it should be played with drumsticks. The students struggled a bit during the workshop interview because the child had very clear ideas about some of the properties of the instrument, while also responding "*I don't know*" when asked questions.

The developed instrument corresponded well to the child's description, apart from the fact that it was not played using drumsticks. Figure 5 shows the final instrument: a repurposed and hacked bongo toy drum with two drumheads emitting red or blue light. The drum "decides for itself" which sound to play on one of the drumheads, using a random function, and plays the theme songs from *Frozen* and *Pippi Longstocking* on the other drumhead. The colored lights (red for *Pippi Longstocking* and blue for *Frozen*) were added to provide a way of learning how to keep a steady beat. The instrument was played using a hitting gesture captured by a piezo element and a pressure sensor. In the written report, the students argued, based on principles for designing for children (Resnick & Silverman, 2005), that it is better to observe and meet children's needs than to give them what they want. Although a drum that plays random sounds is easy to implement, the design would be in conflict with fundamental instrument mapping strategies of predictability (Jordà, 2004); such an implementation results in the inability to anticipate the sound that will be produced next.

Drum instruments typically involve vivid body movements. However, the child did not approach the instrument as though it was a bongo drum. Instead, she kept a distance from the instrument, trying out one sound at a time with her left hand while pressing gently on the drumhead. The students did not try to move her closer to make it easier for her to use combinations of the sensors and controllers, and therefore, the embodied musical experience did not meet its full potential.

Figure 5. The "Maja" instrument is a repurposed toy drum with a piezo element and a pressure sensor below the drumheads. The drum lights up in blue or red according to which song is being played, and the lights also flash to accentuate the rhythm. The image is used with permission.

Instrument 4: "Jomäo"—A Novel Pan Flute

The student-representative asked this child to mention her favorite instrument and color. She described a red traditional pan flute. When asked to draw a picture, the child partly stepped away from the original idea and added buttons. Through a dialogue with the student, the buttons were mapped to playing tones following her description of *"dark"* to *"light."* In the design process, a button was provided to allow switching between a piano- and a flute-inspired sound. Yet, one explicit directive expressed by the child was that the instrument should *"not sound like a pan flute."* The only example of vocal sketching was when the child quietly said *pling* and *ding* in response to the student asking how she felt a piano sounded. The child seemed to prefer drawing rather than using her voice. One detail that was particularized in this instrument was the enigmatic name, "Jomäo" (for which she offered no explanation). The creative process was driven primarily by the student, while the child would approve or disapprove ideas and suggestions. The instrument description could thus evolve toward a design instruction that conformed to the underlying specifications of the project work.

The developed instrument incorporated the visual sketch and the sound design by resembling a pan flute (see Figure 6). It is played using both hands and can be held like a pan flute with four buttons on each side that can be played using the thumbs. In terms of the produced sounds, the child did not want the instrument to sound like a pan flute. Thus, a player can alternate between a processed flute-inspired sound and a processed piano sound. Additional characteristics—such as octave, scale tones, and timbre—were later introduced by the students. The child-directed concept of "dark" to "light" were interpreted as low to high pitch, respectively (in line with, e.g., Dubus & Bresin, 2013).

Played tones were visualized with red and green lights emitted from the otherwise only decorative pipes. In the students' project report, they discussed how the design instruction of a pan flute conflicted with a wish to produce something novel. The liberty taken here was, for instance,

Figure 6. The instrument "Jomäo" has a pan flute-imitating appearance and consists of a button interface. LED lights in red and green indicate which tones that are being played. The photo shows the instrument during the presentation with a microphone to project the sound. The image is used with permission.

to implement polyphony and consider alternative methods for interaction. One design constraint was that the instrument should be easy for the child to hold. As a result, the size- efficient box could only fit a very small loudspeaker placed in the bottom left under the casing with sound propagating from the rounded kerf-cut corners. The small speaker resulted in a distorted sound which further distanced “Jomäo” from acoustical instrument sounds.

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The size of the instrument was appropriate for a child and, when trying the instrument, she held it with both hands, exploring the sounds using her thumbs. To amplify the sound in the performance situation, a microphone was placed near the instrument. One of the students supported the instrument with her hand and positioned the internal speaker close to the microphone (see Figure 6). These unintentional attributes of the performance situation were observed to reduce the child’s possibilities in terms of interaction with the instrument and of the embodied experience.

Instrument 5: “Christiano Ronaldo”—A Button Interface

The child who described this instrument wanted to have soft buttons that could be pushed to generate a range of sounds. Additionally, he successfully vocally sketched multiple times throughout the interview session, producing sounds such as “*click clock,*” “*ding,*” and blowing sounds. This child further tapped the table in order to describe a drum sound. The rows of buttons should play, respectively, melodies, drum sounds, and effect sounds (but no animal sounds). Finally, the child mentioned that the sound should come through headphones only (i.e., no speaker option) and that the volume should be adjustable.

In terms of final design outcome, the instrument corresponded well to the child’s description. The instrument is a yellow and green box with three rows of eight buttons and two sliders (see Figure 7). However, the interviewing student had to ask many leading questions in order to discern how the instrument should actually function. The students also made several suggestions during the design phase about how the instrument could work in terms of incorporating both melody and drum sounds, which might have influenced the sonic outcome. The final design contains two sliders that control a sound-altering effect and the overall sound level. The students’ report mentioned that they had to interpret which sound effects to include in the third row of the interface and to avoid animal sounds. The students also described how they responded in their design process to the child’s vocal sketches with their own vocal sounds, entering a kind of imitation dialogue.

When trying out the instrument, the child initially explored the sounds with one hand. After about a minute, he added the other hand and started combining two sounds. Contrary to the students’ expectations, he did not move the sliders and press the buttons simultaneously. Instead, he used one hand for support or to stabilize the instrument while the other hand was moving a slider. When the child enjoyed the sound he was making, he started to swing his body to follow along with the produced sounds.

Figure 7. The instrument “Christiano Ronaldo” consists of a wooden box with three rows of eight soft rubber buttons and two sliders. The image is used with permission.

DISCUSSION

Collaborating creatively with young children involves specific challenges that may differ from codesigning creative interfaces with adults. Interestingly, our work highlights that although vocal sketching was not used to any great extent by all children in the described codesign task and challenges occurred with this proposed method, it is potentially practicable as a tool with others in a user-centered design task focused on developing DMIs for children. We present here a detailed discussion regarding the use of vocal sketching as a prototyping method with young children, along with a summary of limitations of the presented work and suggestions for improvements in future work.

Our findings suggest that young children should be allowed to use a modality of their own choice when describing instrument designs and exploring potential sound scenarios. Also, we claim that a combined methodology, allowing for multiple modes and means of interaction (drawing, describing sounds and shapes verbally, using props, playing, singing, and acting), provides information that is rich enough for successful DMI design. In our research, based on the children’s reactions and responses in terms of satisfaction and joy, we conclude that they were intrigued by having an instrument built specifically for them. We did not evaluate these observations formally through follow-up interviews. However, even a year later, the teachers and parents have noted repeatedly that the children still remember and talk about their involvement in the project in great detail. In particular, the children still refer to “their own” instruments. With the unreserved confirmation from teachers and parents who expressed a high appreciation of the whole experiment, we are certain that the children felt safe and engaged in the design process.

Using Vocal Sketching in DMI Design with Children

Can vocal sketching be used by young children to communicate sounds? We observed that all the children managed to produce vocal sketches in the preparatory tasks conducted before the workshop.

However, during the workshop, only a couple of them used vocal sketching despite being encouraged to do so. The task of describing a "fantasy instrument" is understandably abstract for young children, and the task of describing or mimicking the sound of an instrument they have never heard is even more difficult. Nevertheless, children are commonly known for their vivid imaginations, boundless play, and immersion in fictional realities; not the least, children perform sound imitations already from prelingual age as part of human cognitive development. Thus, they are indeed capable of relating to abstract concepts that involve sound making at an early age. It is worth noting that the children in the study appeared to have no problems when it came to using other means of communication to describe their envisioned instruments. Most participants provided drawings, gestures, and/or verbal descriptions. A combined methodology allowing for multiple means of communicating their design ideas seemed to be fruitful in terms of exploring potential design solutions, perhaps because this allowed the children to use a modality of their own choice.

One may ask why some children produced vocal sketches while others did not. The children had, allegedly, comparable musical interest and training. However, a span of 22 months is significant in terms of learning, skills, experience, and development for children of this age. However, the low number of participants complicates our ability to address age as a contributing factor. Moreover, the results indicate that the younger participants provided descriptions and imaginative instrument concepts that were on par with the older children. Presumably, individual development and experience could account for larger variations than age and training in this case. We also want to acknowledge the impact that the interviewer (an element that was not controlled in this study) had on the creative setting: We could not predict the child's reaction to the interview situation or how the student interviewer managed in a fluid situation. As such, the above-described factors and the study design involving only a small test group can conceivably explain the differences we experienced.

Regarding communication of sound preferences, at least one child expressed a desire for the envisioned instrument to be able to produce low-frequency sounds. In the context of vocal sketching, we note the constraints in terms of frequency range capabilities of children's voices. The physical properties of the vocal apparatus can thus impact vocal sketches. For example, most children cannot produce low-frequency sounds in the same way as adults. Nevertheless, considering that children are capable of mimicking sounds of big trucks, lions, and other low-frequency sounds, this might not have had a significant effect on the feasibility of using vocal sketching as a design method.

For our study, the user-centered approach involved in converting sketching into functional prototypes could not rely solely on an analysis of the vocal sketches found in the recordings: The quality of recordings obtained from the design workshop were insufficient for building sound models from signal analysis alone or from computed audio features. Ideally, the students would have plentiful vocal sketches within a high sound-to-noise ratio, but the spoken interviews and drawing material obtained from the workshop drew more of their attention. In general, the majority of the DMIs focused on sample-based sound generation, not real-time synthesis, based on verbal descriptions of intended sounds. In future studies, it would be interesting to collect more high-quality recordings of the vocally produced sounds. It would be interesting to explore how existing technologies could be used to support the prototyping sessions, for example, by providing examples of similar sounds, by direct manipulation of the voice, or even real-time synthesis. One could imagine solutions in which machine learning methods could be used to identify sounds similar to the vocal sketches or a scenario in which the researchers engage in an iterative loop that supports the child presenting alternative or clarifying examples of proposed audio effects. Additionally, the software tools for prototyping developed in the above-mentioned SkAT-VG project (Baldan, et al., 2017) perhaps could be adapted to support children as designers. A challenge in this context is that most of the design and prototyping procedures ideally would have to be done in real time.

Engagement in the Task

How suitable is vocal sketching when it comes to engaging children as active participants in a design process? The students reported that the material collected during the workshop was somewhat inadequate in terms of providing guidelines for the DMI designs. However, all groups still managed to interpret the given descriptions and declared concise musical ambitions with their creations. Considering that vocal sketching was not introduced explicitly as a design method to the children and that multimodal descriptions in general appeared to come easily, we believe that the children would not identify one modality as less agreeable than another.

As a confirmation of the correspondence between the description and the final product, we observed during the musical performances that the instruments largely seemed to match the children's expectations. Our interpretation is that even if the communication between students and children could be improved to some extent, some fundamental aspects of the design were salient. What is interesting in this context is how important the sound was for the child in the design process. For example, would a child describing a guitar be satisfied if the students had provided a ukulele, and if not, would this be because of the size, the number of strings, or the sound of the instrument? An immediate related interpretation is that the students could possibly have produced the same instruments without using voice sketching at all as a data-gathering method. This speculation is neither supported nor dismissed from our study. However, it is not unlikely that the whole design process (and hence, the students' learning outcomes) would have been very different without this mode of research.

Another perspective that has not been studied directly here is whether the children felt they could convey their ideas using their voice. As this project was, with all probability, the first time the children were asked to imagine and design a new instrument, we have no reason to believe that they would have been in a position to reflect much on the various methods that were used. The goal of their work—that is, what the instrument would sound and look like—was too abstract.

Perhaps the design instructions could have improved if a teacher had been more involved in the workshop preparation: We observed that the children could perform vocal sketching in the preparatory session where one of the authors participated as a teacher. Moreover, elements of play with the creation of sounds, in which the children easily started to imagine and produce different types of sounds with various tools (including their voice) or probes, potentially could have been beneficial in this case (cf. Mazzone et al., 2010).

Motivation and Bias

From the students' perspective, each team was required to present a DMI that was to be both showcased publicly and assessed as a learning activity in the course. In the interest of deriving appreciation, they possibly focused particular effort on making the design immediately appealing to the child who was to perform with it. However, during the demonstration and performance session, we observed that the students' desire to make a good presentation for the course examiner took away some of the focus that they should have had on the child exploring the instrument. Even in the project reports, the students generally tended to focus on presenting the DMI from a perspective of possibilities of sound production and technical possibilities, rather than discussing the general artistic value of playing music with the instrument or the specific use case of the child for whom it was built. Because this learning activity and the project report were part of a formal course examination, we knowingly introduced a bias in which the students' motivation was not necessarily intrinsic to that of codesigning with children. Thus, even though the course results were good, and the children appeared satisfied, we cannot conclude that vocal sketching is an effective method following the procedure outlined here. Therefore, we suggest changes in the methodology for future work (see below).

In the course's project instructions, we presented vocal sketching as a useful method to gather design instructions from preschool children. However, we took into account the risk that young children might not provide sufficient information. Therefore, we designed both the experiment and the learning activity in such a way that the students would not need to rely solely on the children's vocal sketching. Analysis of the recorded interviews revealed that the students often tried to initiate a discussion with the children by encouraging them to speak about their favorite instrument or favorite color. The reason why these questions were brought up was probably that the children typically did not provide spontaneously any design directives for the instruments or their sounds. In addition, expectations from the participants involved in the workshop—students who hoped to get material, and possibly children who hoped to respond correctly—can become a hindrance to creativity rather than a boost when time is constrained. Thus, the tension from unmet expectations likely affected the interview process and consequently the DMI design.

A Safe and Accommodating Environment

Producing imitations of sounds in front of a stranger can be assumed to be a reasonable challenge, for anyone. Even experienced adult researchers can be challenged when trying to make subjects feel comfortable enough to perform vocal sketching. In the case of vocal sketching with adults, Ekman & Rinott (2010) indicated a warm-up exercise was crucial to making the participants more comfortable with the task, as well as possibly repeated examples in which the instructor demonstrated vocally sketched sounds.

Encouraging participants to use vocal sketching for design also is not trivial and requires preparations, sufficient communication skills, and persistence. The need for inspiring conditions in this context is therefore of great importance, particularly so when designing with children. Consequently, we suggest that in encouraging vocal sketching with untrained or even introverted or shy persons, it is imperative that the setting is well prepared, inviting, creative, and safe. Interestingly, none of the children seemed to be bothered by or even aware of the video cameras, perhaps because of the omnipresence of cameras among parents and in schools nowadays.

The most difficult part of this project appeared to have been the communication of sound preferences between the children and students. One remaining question is to what extent the child and the student-group representative were involved in creating a shared understanding of the sound design. One way to address that is through a combination of multiple methods used when working with children as informants. This way, a child's preferences can be taken into account and the task of designing can be adapted for each child.

Limitations and Suggestions for Future Work

It is possible that the methodology used to introduce vocal sketching in the design workshop could have been improved and that more design directives for the envisioned sounds for the respective instrument could have been collected if certain methodological shortcomings had been addressed. Because the children all managed to sketch sounds vocally in the preparatory session held at the preschool, in which one of the authors and all the pedagogues there participated, it is likely that the interview context with students—outside the children's place of familiarity—had a significant, negative impact on the success of the process. Therefore, future design sessions with children should emphasize developing a safe and encouraging environment for the children and involve more careful preparation of warm-up tasks, possibly with singing and elements of play developed together with music pedagogues who know the children. Moreover, other prototyping methods that incorporate props and sound examples should be explored.

The procedure allowed the child to play the new instrument for only a limited time, approximately 90 minutes, which encompassed the rehearsal, presentation, and the open hands-on session. Additionally, the students knew from the task description that little opportunity was available for the children to develop playing skills. Nevertheless, the designs most likely presented a steeper learning curve than expected, resulting in lower potential for musical expression (see Jordà, 2004), a situation that might have been resolved if more time had been scheduled, particularly for the child's practice with a unique instrument.

It is worth noticing that some of the envisioned sounds described by the children in this study were not necessarily tightly linked to the common notion of what a traditional tonal musical instrument should sound like. For example, the child who created the instrument "I pour soy in the piano" described everyday sounds of eating and the child who created the unicorn instrument "Elsa" described the sound of shaking a pearl in a glass container. These results highlight the potential for children to act as designers of sounds that go beyond the notion of a traditional instrument. The fact that the children used metaphors of sounds from everyday interactions shows the potential for exploring how young children want to engage with musical instruments and what actually can be considered a musical instrument for them. This is an interesting finding, considering that commercial musical instruments for young children commonly provide a rather limited set of tonal sounds and provide little possibility for customization or exploration of complex sound synthesis methods.

Much is still unknown about vocal sketching, especially for particular groups such as young children. Some future directions and developments for experiments could be to study the various research modalities individually, to approach vocal sketching systematically, and to find any correspondence between a design description and the end-product by means of qualified interpretation or experience from parents and teachers. Also, it would be valuable to use a range of methods to produce materials for the design tasks and to educate interviewers who set out to use vocal sketching with children. More studies on communicating sound properties nonlingually with embodied sketching methods should be done in order to get a deeper understanding of how to best approach the task of codesigning with children.

CONCLUSIONS

In this paper, we described a study in which students enrolled in an MSc course on musical communication and music technology engaged preschool children in codesign of novel DMIs. The children used a variety of modalities and techniques to provide design descriptions that were then transformed into working musical prototypes. The prototype instruments were constructed with Bela boards and a range of materials and sensors, depending on the design instructions and the children's needs. The purpose of this study was not to evaluate the DMIs. Rather, it was to explore how university students engaged young children in exploring vocal sketching as a design method—that is, as a means for the children to describe envisioned sounds for a new instrument—as well as a means to assess whether this method is effective in instrument design.

In the current study, we considered not only vocal sketches of envisioned instruments but also other sound-producing actions as well as verbal descriptions of sounds. We found that even if vocal sketching might serve as a potential solution when it comes to communicating sound preferences of young children, ideally the method should be combined with other methodologies for exploring sounds. In this study, vocal sketches provided few design directives for the student instrument builders. Nevertheless, it appears the instruments met the expectations of the children, based on their reactions and those of the teachers and parents present during the workshop. Interestingly, the developed DMIs appeared successful even without some children being able to provide a detailed description of the intended sound, perhaps thanks to the richness of other material collected during interviews with the children, such as paper sketches, gestures, and verbal descriptions of sounds.

The study tasked the MSc students with engaging the children in employing vocal sketching in the challenging setting of an unfamiliar environment outside their preschool. Our findings cannot point to any specific rationale for why, despite the children's successful practice of vocal sketching prior to the instrument design workshop, the method was infrequently applied by the children in the workshop setting, even when prompted. Nevertheless, we suggest that it should be possible to use vocal sketching as a method for engaging in a DMI codesign activity, especially when taking into account that sound imitation is a natural and important part of a child's play from an early age (see, e.g., Kuhl & Meltzoff, 1996). Supporting the findings of Mazzone et al. (2010), we emphasize that vocal sketching should be employed together with a range of other methods in design tasks to accommodate the needs and preferences of the children. Thus, it is essential to prepare the interviewers who set out to encourage children to use vocal sketching in a design task.

IMPLICATIONS FOR RESEARCH, APPLICATION, OR POLICY

Our research raises several implications for future studies employing the vocal sketching method. The importance of training participants to more effectively embody and communicate the methods is a key consideration for future research. Additionally, our study suggests that a variety of methods (e.g., drawing and verbal descriptions) should be used to supplement material when engaging children in a sound-design task. Finally, because sketching instrument sounds vocally is not a simple task, neither for children nor adults, the methodology is particularly dependent on favorable circumstances to work well; thus, additional attention to context, environment, and interaction would be key areas to identify and qualify in future research.

ENDNOTE

1. This author has published previously under the name Kjetil Falkenberg Hansen.

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