SMART MUSICAL MATS:

A MUSICAL UBIQUITOUS COMPUTING ARTIFACT TO SUPPORT BASIC EDUCATION

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ABSTRACT

The problem investigated in our research is the difficulty posed by technical barriers to sound making in the process of learning music, and this problem is located within a sociotechnical context (basic education). In order to investigate the solution to this problem, we have developed a ubiquitous computing artifact, the Smart Musical Mats (SMM). In this article, we present the developed artifact, the results of our research, developed using the Design Science Research approach, and also our thoughts on how this artifact fits within Ubimus.

1 INTRODUCTION

An important part of music education is the making of music by students. However, some musical instruments require difficult techniques to make sounds, and demand a high number of exercises and of practices with repetitive movements which, often, cause students

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to give up on trying to play them. Therefore, one can observe a problem that will need to be faced while implementing music education in Brazilian basic education. How can we support sound making by students in order to decrease technical difficulties and make the process of learning music more pleasant and less dependent on instrument technique? This issue is even more relevant in the first years of basic education, when children have not yet developed aspects of laterality and motor coordination which are essential for playing certain musical instruments. In order to solve this problem, we developed a ubiquitous computing artifact, the Smart Musical Mats, which was also investigated and evaluated in the work of Santos (2015), who is one of the authors of this article and who was also the researcher who conducted the case study presented here.

The technological changes that computers have brought to everyday life are multiplying in several application fields. This multiplicity of options is accentuated when computers also physically spread through the environment. Weiser (1991) foresaw this moment and coined the term Ubiquitous Computing. He understood that computer components becoming smaller would lead to a revolution in our way of perceiving and interacting with computers in our lives: each person would have not only one, but several computing devices. His vision proved right, because today we are living a time when we have not only smartphones, smart tablets and smart game consoles, but also smart personals assistants such as Google Home and Alexa, smartwatches, smart vacuum cleaners, smart locks and smart cars. This new way of interacting with computers brings many possible applications in different areas such as music, education and, consequently, music education.

For over a decade, a research field called Ubimus (Keller et al., 2019) has been investigating different types of concepts, constructs and artifacts linked to the combination of ubiquitous computing technologies and the field of music.

Section 2 deals with what the authors of this article consider music education and its goals. Section 3 deals with Ubiquitous Computing and the developments of its relationship with music, including examples of Ubimus' lines of research and important concepts that have emerged from these researches. Section 4 presents an artifact that was designed and investigated in context in order to support classroom music education in basic education, the Smart Musical Mats, and Section 5 presents the methodological and epistemological aspects of this research. Section 6 presents the results of the investigation and the evaluation of the artifact, and Section 7 contains a few thoughts on the possible relationships between the artifact and Ubimus. Section 8 presents the conclusions of the article, limitations and future works.

2 MUSIC EDUCATION AND THE THEORETICAL FRAMEWORK OF THIS RESEARCH

In order to better understand the goal of music education in basic education, we need to define our understanding of what is music education and how is the relationship of students with music throughout their learning process. Thus, we have established a premise and three conjectures which, derived from our theoretical framework, have guided the design of our artifact.

Our premise consists in the consideration that music is a type of discourse, and that music education's objective is to make students literate in musical discourse. The three theoretical conjectures that were brought from our theoretical framework were based in the relationship between the technical demands of sound production and the musical learning process, in the social aspect of education and in the use of the body and its movements in developing music education. Below, we present the premise and theoretical conjectures that guided the development of the artifact presented in this article.

2.1.1 MUSIC AS DISCOURSE

Music is a sequence of sounds in which different sounds cause listeners to experience different sensations, emotions and thoughts. Thus, we can understand music as a manifestation that belongs both to the physical universe of sounds and to the emotional and cognitive universe. Some authors believe that music has a communicational side and that it is similar to language in some aspects.

2.1.2 SWANWICK'S MUSICAL DISCOURSE

Swanwick (1979) presents the notion of musical discourse. Thus, for him, music is composed of sound elements that are combined according to a common value and a common intention perceived by the participants, who are within a creative process that must be fluid and contain meaning. He presents a few important concepts regarding the most basic elements of musical discourse, which we describe below:

- **Materials** are any sounds that can be perceived, but are not intentional and do not have a relational character, such as, for example, the sound of rain, the sound of a glass breaking, a musical note (of a given pitch) played randomly (such as when a musician tunes his or her instrument).

- **Elements** are any sound materials which, due to the intention of the player, acquire a relational character and become an element of the musical discourse.

In order to reach the level of musical element, the material must have three different conditions (Swanwick, 1979):

- **Selection** – In order to build a musical object, one must choose certain sounds and discard others. Not all available sounds are selected, and there are situations in which certain sounds can be discarded and others, repeated.

- **Relation** – The chosen sounds must have a given relationship with one another in time.

- **Intention** – The composer/performer must have the intention of making music.

The way in which sound making occurs in a musical instrument has a direct impact on the student's ability to make sound materials and in their transformation in musical elements that can be used to build musical discourse.

Therefore, the difficulty faced by the student in making sounds using a given musical instrument will influence their way of expressing themselves and of participating in building musical discourse.

2.2 DECREASING TECHNICAL BARRIERS TO THE BUILDING OF MUSICAL DISCOURSE

Educators such as Orff (Frazee & Kreuter, 1997) tried to make sound making easier by offering students instruments such as the metallophone and the xylophone, since they allow sound making without a great deal of technical effort. The xylophone is also built with bars that can be removed, and it can be configured so as to avoid certain mistakes on the part of the student on a given exercise: for example, with the removal of certain bars, you can leave only the specific subset of notes with which they will work in that class. By doing this, you avoid technical performance issues such as exceeding notes that can lead the student to make a mistake. Thus, we consider our first conjecture: decreasing technical barriers in sound making supports musical discourse literacy. The research problem is related to this first conjecture.

2.3 THE SOCIAL ASPECT OF EDUCATION

To Vygotsky (1989), social interaction is determinant in the learning process. The subjects and the object of knowledge create different types of relationships that include interactions between a subject and the object being studied, among other subjects and the same object and, most importantly, among one subject and the other subjects that interact with that object. The social and collaborative relationships among subjects potentialize and intensify the discoveries regarding the objects being studied. Based in his studies and researches on social interactions and learning, Vygotsky then elaborates the concept of Zone of Proximal Development (ZPD) as being:

> (...) the distance between the real development level "of the child", determined by independent problem solving, and the potential development level determined by problem solving under the guidance of adults or in collaboration with more knowledgeable others. (Vygostsky, 1989, p. 86).

The learning process, then, is a cultural consequence, derived from the contact among the subject and other subjects who also manipulate and experiment with the objects of study. Based on this characteristic of education formulated by Vygotsky, we have arrived at our second conjecture: *collaboration supports musical discourse literacy*.

2.4 THE RELATIONSHIP BETWEEN THE BODY AND THE MUSIC LEARNING PROCESS

Authors such as Dalcroze (1921) and Orff (Frazee & Kreuter, 1997) also defended the use of the body and the use of movement through gestures as mediators of the music learning process, supporting the understanding and the assimilation of musical discourse. Learning activities that privilege both intellectual and physical aspects have a greater impact in the perception and in the learning process of individuals involved. Supported by these authors, our third conjecture is: the use of the body and its movements supports musical discourse literacy.

After presenting our understanding of the relationship between people and musical discourse, in the following section we will discuss the possibilities of computer musical artifacts that can be built using the technological advances in the field of computing that occurred in the last few years.

3 MUSIC AND UBIQUITOUS COMPUTING

The relationship between music and ubiquitous computing is relatively recent and has been investigated for over a decade. "Ubiquitous music is, in practice, music (or musical activities) supported by Ubiquitous Computing concepts and technologies" (Pimenta et al., 2015). Ubimus' research is characterized by different fields of knowledge and investigation, including "sound and music computing, human-computer interfaces, studies about creativity and music education, with a strong social and communitarian component in its practices" (Keller et al, 2019). These researches deal with the participation in artistic musical contexts (Keller & Capasso, 2006) and in educational contexts (Lima, Keller & Flores, 2018; Keller & de Lima, 2018; Miletto et al., 2011) by both laypeople and subjects who are already familiar with music technique, such as professional musicians or experts.

Important concepts are present in Ubimus' research, such as everyday musical creativity and ecological-cognitive creative practices. Based on the concepts of little-c creativity

(Richards, 2007), Keller et al. (2013) state that everyday musical creativity is a specific form of everyday creativity that is “derived from creative sound processes and products that occur in the everyday life of musicians and laypeople outside of environments specifically designed for the making of music.”. Ecological-cognitive creative practices are the result of the interaction between subjects, with their cognitive processes, and the material resources present in their environment (Keller & Lazzarini, 2017).

Keller and Barreiro (2018) also call attention to the existence of two predominant forces of attraction in Ubimus’ research: studies about everyday (musical) creativity and new ways to make music.

The first force of attraction is everyday creative practices, in which there are issues related to user profiles and the changes that these different profiles cause on the design of the interactions present in systems developed by Ubimus. Users who can be considered laypeople regarding musical knowledge and ability create demands that are different from those created by experienced users. Therefore, different types of system can be developed to meet the demands of specific user profiles. However, problems can arise when two different student profiles are mixed in the same musical activity, a situation that still needs to be investigated and evaluated. A possible solution to this problem is the creation of knowledge transfer strategies among laypeople and experts through gesture cues made by body movements (Keller, Aliel & Siva, 2018). Another possible solution to the same problem is the implicit knowledge transfer among participants supported by verbal language, in avoiding the use of specific musical technical terms. This latter approach can also lead to the inclusion of semantic cues in Ubimus' ecosystems, an example of which is the tool Playsound.space (Stolfi et al, 2018).

The second force of attraction is new ways of making music, and this force has three different aspects:

1. The change in the limits of the interactions among composers, audience and performers during musical performance.

2. The potential impact of Ubimus in human development and in the wellbeing of its users.

3. The influence of ubiquitous computing techniques in the development of Ubimus.

Regarding the third aspect mentioned previously, the advances in ubiquitous computing allowed the emergence of different technologies such as 3D printing, laser cutting and the use of microcontrollers and processors that can, due to their small size, be placed in different locations and objects. Maker culture and the concept of DIY became a part of possible Ubimus practices.

Brown & Ferguson (2024) bring up good questions about the use of digital fabrication technologies and the use of ubiquitous computing to build sound instruments. In the case of their instrument, Analogue Revolutions, the authors built it using integrated circuits (ICs) and passive components, stating "*there are no programmable (PIC) chips and thus no computer is involved.*". In the case of another instrument, Sonic Frisbee, the authors' objective was to use it in workshops and other pedagogical situations that include both sound-musical practice and the maker culture practices of becoming familiarized with welding processes and of making sounds with electronic components. Their other creation, Quadra, is a kind of *Groovebox1* more appropriate for being used by composers than performers. The authors used laser cutting machines to build the printed circuit boards (PCB) that were used in these sound instruments.

Merendino (2004) built the Dispositivo Cinetico Midi (DCM), a digital sound instrument that has buttons that can be finger-activated, but added motion sensors, using a gyroscope, that allow a larger number of gestures to influence in sound production. Merendino (2024) also presented an instrument named Sonic Cubes in which cubes made out of fabric have an esp32 microcontroller inside. Each cube is wrapped in a piece of fabric that has conductive thread running through it and acts like a user touch sensor. When they are moved, the cubes send data captured from the gyroscope to a computer, in the same environment via Bluetooth, and produce sounds.

4 SMART MUSICAL MATS

The developed artifact, named Smart Musical Mats (Santos, 2015), is composed by a set which contains something that is a part of everyday school life, the EVA foam mats, a hardware and a software. We gave one object – the mats – a certain degree of intelligence, connecting it to different computing elements and sensors, all of which need to be present in the classroom.

When we consider the taxonomy proposed by López and his collaborators (2009), the artifact Smart Musical Mats presents abilities 1 (it has a unique identity), 2 (it perceives changes in the environment, i.e. electric circuits closing), 3 (it acts on the environment, making sounds) and 4 (it decides which sounds to make depending on the perception of which electric contact was closed).

4.1 THE OBJECT OR MAT

Squares of EVA foam shaped like pieces of a puzzle are an everyday object on different segments of education. From day-care to secondary school, we can observe these objects being used for classroom decoration, to protect children from falls and in games and playful activities in general. These EVA foam squares are usually sold in sets, for example of four, six, ten or twelve, and are often used to make carpets. Thus, in this article, we have considered each square as a mat and called our artifact Mats, plural, because it needs at least two squares to work. On Smart Musical Mats, each mat is connected to the hardware. EVA foam mats are inert objects. The hardware and the software connected to them is what makes them a smart object with which subjects can interact.

4.2 THE HARDWARE

The hardware built during this research is composed by the following parts: a computer, electric wires, aluminium foil sheets, a Makey Makey (2020) board, which will provide the system input, and loudspeakers, which will be the system output.

The Makey Makey board has an electric configuration with eighteen signal input pins and also ground pins. This board has an embedded ATmega32U4 microprocessor, the same one used on the Arduino Leonardo, which allows it to emulate key presses and mouse movements using the HID (Human Interface Device) protocol. These mouse movement or key press commands are turned on when the electric circuits are closed by the presence of any minimally conducting material. Thus, each pair of input and ground pins works as an on/off switch, which begins or interrupts a HID command addressed to the computer to which the Makey Makey is connected.

In the case of the Smart Musical Mats, we used the human body as the conducting material that closes the contact between an input and a ground pin. More specifically, we used two people, each connected to a wire. When they touch each other, they close the circuit associated with them. Working in pairs, each person, barefoot or wearing socks, stands on the aluminium foil sheet over a mat (Figure 1). The sheet connects to a wire that is extended to an input pin on the Makey Makey board.

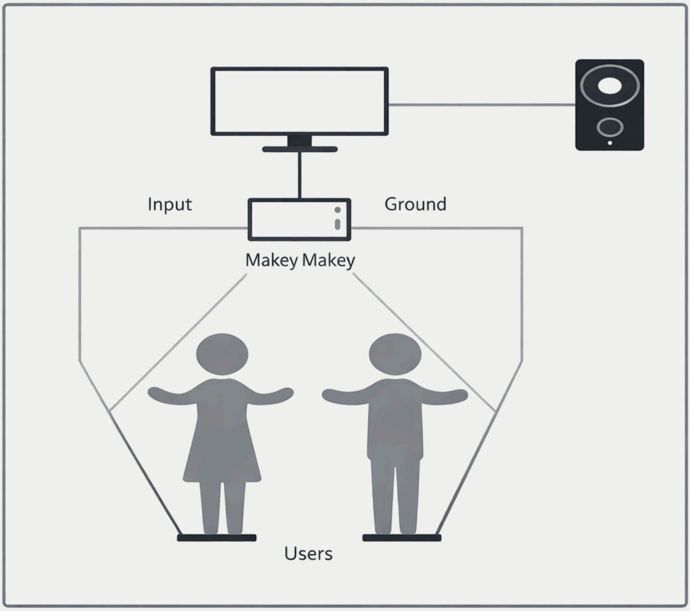

FIGURE 1. STUDENTS POSITIONED OVER THE MATS

4.3 THE SOFTWARE

Soundplant (2020) is a proprietary software, but it has a free version which was used in this research. This software addresses different audio samples (in formats such as wav, aiff, mp3) to the computer keys and, when one key is pressed, a specific sound is triggered. The Makey Makey board, then, can activate the Soundplant software, and the audio samples chosen by the users are triggered in the computer and heard through loudspeakers.

5 METHODOLOGICAL AND EPISTEMOLOGICAL ASPECTS OF THE RESEARCH

The production of knowledge about the development of artifacts is the objective of the Sciences of the Artificial (Simon, 1969), which must be studied in a different manner from the Natural Sciences and the Social Sciences. Since this work investigates an artifact that does not exist in nature, but was created by man, we understand that this research is part of the Sciences of the Artificial, as detailed in this section.

5.1 METHODOLOGY-EPISTEMOLOGY

The technical knowledge generated during the making of an artifact is different from the scientific knowledge generated by a research (Pimentel et al, 2020). In order to do a research that generates scientific knowledge during the development of our artifact, we used the epistemological-methodological approach Design Science Research – DSR (Hevner et al, 2010) (Figure 2). This approach, which is based on the Sciences of the Artificial, has the double objective of: (1) developing an artifact to solve a practical problem within a specific context and (2) generate new technical and scientific knowledge (Dresch et al., 2015). In a research that uses the DSR approach, the development of the artifact supports the advance of the theory on user behaviour, which, in its turn, supports the development of the artifact. This occurs on an iterative process in which both are mutually refined. In DSR, one uses the abductive thought typical of a projective work, in which alternatives are identified and solutions are selected, differently from what occurs in inductive, deductive or hypothetical-deductive thought.

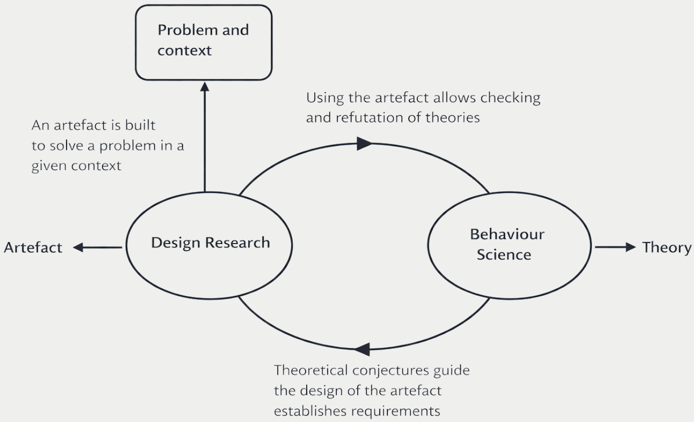

FIGURE 2. DSR ELEMENTS

In this research, we developed a didactic musical object (Design Research) denominated Smart Musical Mats (Artifact) in order to solve the difficulties imposed by the technical barriers to sound making in the process of learning music (Problem) within the sociotechnical environment of basic education (Context). At the same time, during the development of the artifact, we investigated theoretical conjectures about the process of teaching music based on the uses and the relationships of participants with this artifact (Behaviour Research) within this new context in which we utilize an artifact supported by ubiquitous computing technology. Thus, this research deals with a real problem, an artifact that aims to solve this problem, the development of this artifact, and the behaviour of those who use it.

5.2 DATA PRODUCTION

We used the Case Study research method following a qualitative approach with an interpretationist epistemological position (Yin, 2015; Pimentel et al., 2017) typically used in the Social Sciences: its objective is deriving values and knowledge about people's behaviour in a given context through the interaction of the researcher with the research participants. The case study was done in two year 7 classes in municipal schools located in the city of Rio de Janeiro, in Brazil, with a total of 75 students.

This case study began with a conversation with the teacher of each school, which allowed the author to watch one the classes. After this initial contact, four educational activities were developed to support the investigation of acceptance and use of the artifact, and the investigation of our theoretical conjectures on how people learn music. The same four activities were performed in both schools as pedagogical workshops that took place during music classes. These activities, performed throughout a period of approximately three months during the year 2014, were led by one of the authors of this research under the supervision and with the support of the music teachers of both classes.

The technique of data production was performed at the end of the four activities through a questionnaire and a focus group for the students, and through interviews with the teachers. Another technique used was the direct observation by one of the authors of the activity while it was happening and, later, through a video recording of it.

The questionnaire was composed by close-ended questions and open-ended questions that were related to the student profile and their previous music experience. The focus group questions meant to find what the students thought of the equipment, whether they had any difficulty using it, what they learned from the activity and whether they would like to have another class that included the artifact.

The questions of the interviews with the teachers were semi structured, with defined topics that were discussed freely. The topics regarded the teachers' views on music education within basic education with the arrival of Law no. 11.796/ 2008, the use that their students made of the artifact and whether or not they would like to use the artifact in their classes.

We used the Method of Clarification of the Subjacent Discourse (Nicolaci-da Costa, 2007) to analyse and interpret the data obtained from the focus group and from the interviews with the teachers.

This research was approved by the ethics committee of the Federal University of the State of Rio de Janeiro under the report number 893.135 given by the Report Office on 11/26/2014.

5.3 PEDAGOGICAL WORKSHOP ACTIVITIES

We organized four musical activities to be performed during the pedagogical workshop done for the case study. The activities were designed to support different aspects of music education mentioned in the National Curriculum Parameters (PCNs, 1998) presented by the Brazilian Ministry of Education.

5.3.1 RHYTHMIC ACTIVITY

The rhythmic activity (Figure 3) involves the pulse and its divisions in the composition of rhythms, and the appreciation of characteristic sounds (timbres) of different instruments used in the rhythmic accompaniment made by a drum kit (bass drum, snare and hi-hat). In this rhythmic activity, we used three pairs of mats with one drum sound for each pair (bass drum, snare and hi-hat). The students took turns so that all could try using the artifact and producing the required sounds (Execution). Three rhythmic lines were presented to the students using handclaps only, so that later they could be played using the artifact (Appreciation). The three rhythmic lines were built (Composition) in order to accompany songs with which the teachers of each school were working.

FIGURE 3. STUDENTS DURING THE RHYTHMIC ACTIVITY

5.3.2 MELODIC ACTIVITY

The melodic activity (Figure 4) involves listening to the sound of different musical instruments (bass and violin) and perceiving the major scale accompanied by the performance of cyclical melodies (ostinatos) among groups of students. In this activity, we distributed ten pairs of mats, with each mat representing one of ten notes played by a violin (C3 to E4). First, we asked students to play the sequence of notes from the lowest to the highest pitch. Then, two groups, each with five pairs of mats, were given the task of creating melodic sequences (Composition) so that the class could appreciate their compositions (Appreciation). The sequences were performed following the pulse played by the teacher and the claps, and later the students were given more rhythmic freedom (Execution).

FIGURE 4. STUDENTS DURING THE MELODIC ACTIVITY

5.3.3 HARMONIC ACTIVITY

The harmonic activity involves the perception of the difference between single notes and chords, the concept of a block chord and an arpeggio and the harmonic accompaniment of melodies (Appreciation). We used the same structure of ten pairs of mats as in the melodic activity. Each group of five pairs contains the four notes of a tetrad (a four-note chord), with one note per pair. The last pair of mats has the sound of the chord with all notes played simultaneously (block chord). The notes had to be played as an arpeggio by the students using the first four mats and, afterwards, the fifth pair had to play the full block chord, so that they could perceive the difference between the block chord and the arpeggio (Execution). In this activity, we used piano sounds. In the beginning, the rhythm was fixed, following the same pulse, but later the students were given more freedom. Afterwards, we did a variation of the activity and changed the sounds for each pair of mats. One group of mats contained three chords (C major triad, F major triad and G major triad) distributed over three pairs. Two of the five pairs were not used in this variation of the activity. The other group of five pairs was configured with five vibraphone sounds containing the notes of the C pentatonic scale (C3, D3, E3, G3, A3). The teacher asked the students of each group to create their sequences freely using the notes, chords and rhythms (Composition), so that everyone in the class could hear a melody accompanied by chords.

5.3.4 ORCHESTRA ACTIVITY

This activity's objective was joining the rhythmic, melodic and harmonic elements involved in the other activities and allowing the students to accompany the song being taught in the class by the teacher with a rhythmic, melodic and harmonic basis. The focus of this activity was performance and rhythmic activity, not composition, as proposed in the melodic and harmonic activities. Another objective was developing the melodic memory of students and showing the difference between accompanying and singing a song.

In this activity, we distributed sounds of different instruments among the pairs of mats (Figure 5) so that all the rhythmic, melodic and harmonic elements involved in previous activities were combined. One group had the drum sounds, another group had the bass sounds and another group had the chords played by a piano. The class was split in two larger groups and, while one sang the song, the other accompanied it with the sounds of drums, bass and chords. Afterwards, the two larger groups switched: those that were singing began accompanying, and those that were accompanying began singing.

FIGURE 5. STUDENTS DURING THE ORCHESTRA ACTIVITY

5.4 EVALUATION OF THE ARTIFACT

We did three evaluations with the artifact: acceptance of the artifact by users, whether or not the artifact solved the problem of technical barriers to sound making with an instrument, and an evaluation of the conjectures about music education brought from our theoretical framework.

5.4.1 ACCEPTANCE OF THE ARTIFACT BY USERS

Venkatesh and his collaborators (2003) investigated different models of technology acceptance and synthesized eight of these models: the Theory of Reasoned Action (TRA), the Technology Acceptance Model (TAM), the Theory of Planned Behavior (TPB), a model combining TAM and TPB, the Innovation Diffusion Theory, the Social Cognitive Theory, the Motivational Model (MM) and the Model of PC utilization (MPCU). As a result of the synthesis of these models, the authors presented the Unified Theory of Acceptance and Use of Technology (UTAUT). The UTAUT model was developed in order to investigate technology acceptance and usage in a business context, with four constructs being considered: *Performance Expectancy, Effort Expectancy, Social Influence* and *Facilitating Conditions*. The three first constructs influence the *Behavioural Intention*, another variable that influences *Use Behaviour*. The *Facilitating Conditions* construct directly influences *Use Behaviour*.

Later, Venkatesh and his collaborators (2012) proposed the UTAUT2, an extension of the UTAUT model, adding three other constructs that influence technology acceptance and use by consumers: Hedonic Motivation, Price Value and Habit.

In order to evaluate the acceptance of the artifact, we used the extended technology acceptance model UTAUT2 and considered that the artifact Smart Musical Mats should meet the following constructs: having good performance (allowing the adequate exploration of musical discourse), having low use effort (being easy to use), promoting hedonic motivation (being fun to use), leading to use behaviour (making students want to use it in other classes) and having low cost. We did not consider Habit as a relevant construct for the artifact proposed here, because this specific artifact had never been built before. Regarding the Social Influence construct, we consider that society, parents and students already, to a certain extent, pressure schools to use computing technologies in education and, thus, the fact that we are designing an ubiquitous computing artifact would already lead to use behaviour; therefore, this construct was not investigated in the study done with the artifact, even though it has a positive influence over its adoption. The model also includes the construct Facilitating Conditions, which deals with how easy to build and operate is the artifact, and this construct was evaluated in the interviews with the teachers. These constructs guided the questionnaire's questions and the questions asked during the focus group and the interviews with the teachers.

5.4.2 EVALUATION OF THEORETICAL CONJECTURES AND RESEARCH PROBLEM SOLUTION

The evaluation of theoretical conjectures was done through the direct observation and the participation of the researcher, who is one of the authors of this article, during the musical activities performed in the workshops and later through the examination of the videos recorded during the activities. The evaluation was also based on the data extracted from the focus group composed by students and the interviews done with the classes' music teachers. The objective of these evaluations was answering if our three theoretical conjectures were valid:

- *Conjecture 1 – decreasing technical barriers in sound making supports musical discourse literacy.*

- *Conjecture 2 – collaboration supports musical discourse literacy.*

- *Conjecture 3 – the use of the body and its movements supports musical discourse literacy.*

6 RESULTS

Here, we will present the reports from students considering our three theoretical conjectures and the constructs of the UTAUT2 technology acceptance model. The analysis of all this information will allow us to evaluate whether our artifact solved the research problem. At the end of this section, the results of the questionnaire given to the students will also be presented.

6.1 DECREASING TECHNICAL BARRIERS SUPPORTS MUSICAL LITERACY

Students thought the artifact made sound making easy and that they could pay attention to the musical discourse: *"I just had to wait for the right moment to clap. Sometimes it was hard, but then I started to get it"*. In the interview with the teacher of this class, the researcher asked whether he thought that it was easy for students to use the artifact, and he considered that the difficulty of making music with the artifact is the same as with any other instrument: *"I think they had the usual difficulties a person has when they're learning a new instrument. They have that initial block, but then it starts to develop more easily"*. However, the students had a different opinion and considered that the artifact was easier to play than traditional musical instruments: *"I liked it because it's a technological instrument and it's easier to play. Before you learn how to play an instrument, it's kind of hard and you have to practice. I liked participating in an experiment like this one"*; *"I thought it was cool, because I thought it was easier to play and easier to learn. It's easier to pay attention* *because with the others, with traditional instruments, it takes too long to learn".* Since most of the students have traditional musical instruments at home (according to one of the results of the questionnaire), the opinions of these students are based on experience, which indicates that the artifact really allowed them to make sounds more easily than traditional instruments. This indicates that the artifact contributes to the solution of our research problem, although we cannot unequivocally state that it has been solved. Future works can investigate the use of this artifact in other contexts, giving a better understanding of the solution of the problem that originated this research.

6.2 COLLABORATION SUPPORTS MUSICAL DISCOURSE LITERACY

A few of the students highlighted the interaction established with their classmates: *"I liked it a lot because it's very… I interacted a lot."; "I thought it was really interesting (…) Especially because we work as a group and the sound is much better. It's not just one person working alone. Instead of learning stuff by heart, we get the rhythm, so it's more interesting".* These statements identify the social aspect of building musical discourse.

In the interview with the teacher of one the classes, he emphasized the importance of collaboration among students in the learning process: *"I saw students collaborating a lot! You can use more than one child to make a sound. (…) The coolest thing is that a student depends on another to make the sound. If one of them has more ability and other has less, it can make things a little difficult in the beginning, but then there's also the issue of one helping the other develop."*

6.3. THE USE OF THE BODY SUPPORTS MUSICAL LITERACY

The use of the body was highly exercised during the activities. Students used movements to express themselves and a lot of them identified these movements with the learning process: “I learned the rhythms through the body movements”; “I learned motor coordination, how to keep time, before, I didn’t play at the right time. Even the teacher complained that we played too fast, but then we got used to it and got better”; I learned motor coordination and the time for each note [claps]. Synchronizing is waiting for the right moment to clap”.

The researcher also observed a situation in which two students who were not using the mats danced to the music, and another in which a student, after the activity, tried to make sounds sliding his body through the floor until he reached the mats in different ways. The way the mats were arranged in the classroom environment allowed students to change position and move freely, interacting with the artifact and also with their classmates during the learning process. A few students used movement strategies to fill pauses between the sounds played in their activities, indicating that their bodies and their movements were used to build the musical discourse in an active and also in an authorial manner.

6.4 ACCEPTANCE OF THE ARTIFACT

Regarding Performance Expectancy, the activities done with the artifact allowed a large variety of learning experiences among students. A few students highlighted what they had learned during the activities: *“I learned the chords, the times* *we use. I don't know… I learned how to play the instruments without having to use the real ones".* Regarding *use effort,* students stated that *"In the beginning it was hard to follow the rhythm, but then I got it right"; "In the beginning my coordination wasn't good and I played too fast. But then it got better".* Even if they had initial difficulties, students didn't feel intimidated and wanted to explore the artifact. *"It was a little difficult, but it wasn't difficult like… oh… that was really hard".*

Regarding *Hedonic Motivation*, students stated: *"To me that's a new instrument and I liked it a lot, a lot, a lot!!"; "At first, I thought it wasn't going to work. Me, making music with my hands!! [laughs] But then I saw that it was really fun and cool and that we learn. In the beginning, I was afraid to get shocked".*

The only construct that did not get good results in the investigations was Facilitating Conditions. Our artifact is a prototype and needs improvements in some aspects of its setup process so that anyone who is not an expert in informatics can set it up to perform activities quickly and easily. In the interviews, the teachers said that they liked the activities and that they liked seeing the artifact being used by students, but that they did not feel able to set it up without help. Thus, future investigations could focus on other ways to set up the artifact in order to make it easier to use for teachers with basic computer knowledge.

Regarding low cost, all the materials involved in building the SMM are cheap and easy to find: electric wires, aluminium foil, duct tape, EVA foam mats, adhesive tape. A Makey Makey board costs less than £40,00 and Soundplant has a free version. A pair of mats ready to be connected to a

Makey Makey board costs approximately £4,00. These costs are perfectly feasible for most municipal schools in Rio de Janeiro and in several other medium-sized and large-sized cities in Brazil.

6.5 QUESTIONNAIRE DATA

We gave students a questionnaire to answer after the last workshop activity. The first part of the questionnaire had questions about the students' profiles and the second part had questions about the activities and the use of the artifact. While some students answered the questionnaire, others were simultaneously interviewed in the focus group, so that the data collecting process took less time and did not hinder the schools' schedule and the classes planned by other teachers. The questions in the second part of the questionnaire presented answer alternatives in a Likert scale with five values dealing with issues such as difficulty, joy and satisfaction regarding the activities and the use of the artifact.

On *School 1*, 75% of students had between 12 and 13 years of age, and 54% were male. On this school, 68% already had a musical instrument at home and 61% learned music exclusively at school. On *School 2*, 46% of the students had 13 years of age and the remaining students had 12 years of age. 46% were female. 69% of the students of this school did not have musical instruments at home and 77% learned music exclusively at school.

Regarding the activities with the use of the artifact on *School 1*, 60% of students thought they were easy and 10% thought they were difficult. On School 2, 85% of students thought they were easy and none of them thought they were difficult. Regarding joy in using the artifact in the activities, two questions were asked: whether it was pleasant and whether it was fun. On School 1, 71% of students thought it was pleasant and 10% thought it was unpleasant. 71% thought it was fun and 10% thought it was boring. On School 2, 69% of students thought it was pleasant and 8% thought it was unpleasant, while 69% thought it was fun and 15% thought it was boring. When asked if they intended to use the artifact again, on School 1 75% answered yes and 25% answered no. On School 2, 85% answered yes and 8% answered no. These answers support the analyses about the UTAUT2 constructs Performance Expectancy, Hedonic Motivation and Use Behaviour, indicating that the experience of using the artifact was easy to perform, pleasant and made most participants want to use the artifact again.

These results, when evaluated along with the data gathered by the focus group and the interviews with the teachers, indicate that the artifact has acceptance potential among students and teachers.

7 THOUGHTS ON THE SMART MUSICAL MATS AND UBIMUS

After presenting the artifact and the research with which it was possible to evaluate and investigate its use by secondary school students, we had some thoughts regarding how to relate this artifact and Ubimus. Our analysis is based on the two forces of attraction proposed by Keller and Barreiro (2018) in Ubimus' researches. We believe that the artifact has potential to fit into both forces of attraction.

Regarding the first force of attraction, everyday creative practices, the artifact presented here can support formal music education practices, such as the music learning process and the building of musical discourse in the music classroom. The artifact's use in the school environment, as evidenced by the fun and pleasant characteristics demonstrated on the focus group and observed in the classroom and in the recorded video, shows that the artifact also has the potential to support musical practices that do not have pedagogical intention or design, inside and outside the school. In the second case, there are opportunities for future works that can also investigate the mingling of different user profiles when it comes to musical experience.

Regarding the second force of attraction and more specifically its third aspect, the influence of ubiquitous computing techniques in the development of Ubimus, we have other considerations about the new relationships between musical instruments and those who play them.

Since the invention of the first musical instruments, such as flutes made out of bones or drums carved in trunks or in the ground, human beings had to adjust to the acoustic characteristics of their environment and, especially, to the physical characteristics of the musical instrument chosen to intervene in this environment. It was necessary to create an instrument to translate the sound intentions of a subject into sound vibrations that altered the environment, be it through the vibration of strings, membranes or air columns. With time, the techniques of instrument production developed, but some of the mechanic-acoustic characteristics of instruments were impossible to change. For example, it would be impossible to build an ukulele that sounded like a bass and produced the same notes. Sound making and sound performance technique are confined to the physical characteristics of acoustic instruments (such as shape and constituting materials), because these characteristics physically interact with the environment in order to produce sounds. There are several postural consequences of the relationship between the body of the player and the musical instrument they are playing, and human beings, for a long time, were dependent on the physical characteristic of instruments in order to learn how to use their bodies to activate them. Thus, the body of the person conforms to the body of the instrument. In order for this to occur, the player, whether they are a professional or a layperson, has to understand how the instrument of their choice produces sound, and also learn the necessary technique to produce sounds with that instrument.

The advent of synthesizers and computers allowed different timbres from different instruments to be played in a single instrument (keyboard), but the player still had to adjust to the shape of this single instrument.

Therefore, in our understanding, Ubimus presents new possibilities of interaction between the body of the user and the instrument and, also, regarding the ways in which users collaborate. With Ubimus techniques, we can adjust the digital instrument to the characteristics of the user's body, inverting the ergonomic relationships between player and instrument. We can also adjust the artifact to the environment where the activities will occur. As we showed with the Smart Musical Mats, it is possible to decrease technical barriers in sound making and promoting collective interaction in sound making, creating more alternatives for building musical discourse. The access of laypeople to music becomes wider, and music becomes something that can be democratically shared not only through its execution, but also through the possibility of building one's own musical discourse.

The article written by Brown & Ferguson (2024) includes great expectations of popularizing the process of building sound instruments with electronic components, custom-made PCBs and microcontrollers and processors using the possibilities of the DIY approaches in Ubimus. However, these approaches are based on sound instruments which, although they can be hacked, reprogrammed and built by a public with a knowledge of electronics and of the use of certain digital manufacturing technologies, make certain ergonomic demands of their users in the sense of not exploring body movements more intensely during the performance. In a way, they constitute other options of using the fingers and the hands to connect with sounds and, even though there are some innovations in the manner in which sounds are synthetized using microcontrollers and other bespoke hardware, they do not seem to facilitate new body instrument relationships during sound production. The article written by Merendino (2024) deals with this issue of the body by presenting two instruments that can modify sound aspects as a response to other physical gestures. Both the Dispositivo Cinetico Midi and the Sonic Cubes use user gestures that go beyond finger movement, so characteristic of acoustic instruments such as the piano and the flute, in order to influence sound result.

Another issue presented in these articles published in the Journal of Ubiquitous Music (2024) is the gradual extinction of the line that used to separate the instrument builder from the performer that used the instrument.

Ubiquitous computing technologies, digital manufacturing technologies and maker culture applied in DYI initiatives in Ubimus have contributed to the emergence of the Designer-Performer, overcoming the dichotomy present in the case of acoustic instruments with the Luthier and the Player. When I designed and built the Smart Musical Mats, I also had in mind creating a sound instrument that I could explore with my elementary school students, supporting their musical education. Therefore, I became a different kind of centaur, one with three parts: a third musician, a third teacher and a third designer. After all, what led me to this were musical, pedagogical and technological issues. And these issues feed each other in constant dialectics in the process of investigating and building the Smart Musical Mats.

8 CONCLUSION

Our research problem is directly linked to our first conjecture about decreasing technical barriers in sound making to support musical literacy. In order to do that, we developed an artifact at the same time that we developed our research, in which we used the Design Science Research approach. In our evaluation of the results, we noted that the decrease of technical barriers in sound making occurred, and that students were able to build their musical discourse without much effort. Therefore, we consider that our problem was solved. From now on, we believe that it is necessary to investigate how the artifact performs in other contexts besides year 7 classes of municipal schools in Rio de Janeiro, so that we can have more trust in the tendencies presented here.

Regarding the acceptance of the SMM by students, we observed that the artifact has acceptance potential and that its use in different contexts by users with different profiles can serve as a basis for future investigation. We feel it is important to note that the proposed artifact does not mean to be a substitute for traditional musical instruments, but an alternative to increase the options available for students to build musical discourse in the school environment.

The artifact also encourages collaboration between students and the use of their bodies and body movements, as well as the bodies and body movements of others in building musical discourse. We shaped the artifact to adjust it to the users' bodies, but this artifact can also be adjusted according to the characteristics of the environment where the activity will occur, such as a classroom. This fact also creates developments in the ways in which users collaborate while experimenting with ubiquitous computing musical systems such as SMM (Santos, 2015).

The possible physical configurations in the arrangement of the artifact in the classroom allow users to move freely and observe the movements of other participants, which increments interactions and the formulation of hypotheses about the building of musical discourse. Since sound making with the artifact does not demand a great deal of cognitive effort, users can pay attention to their environment and exchange information with other users, be it they verbal or gestural.

More importantly, the decrease of technical barriers in sound making allows the understanding and application of musical concepts, and allows the communicational intentions and expressions of each subject to be channelled and concretized through the building of their musical discourse.

LIMITATIONS AND FUTURE WORKS

One limitation present in this version of the artefact is that the user, while making sounds, cannot alter the volume of the available sound samples. This way, musical issues regarding dynamics cannot yet be explored in this version of SMM and may be investigated in future researches.

A possible line of future investigation is the use of visual recognition to detect gestures to give inputs in sound parameters such as the volume of each sound produced with the artefact or even to allow the triggering of sound samples.

Another possible line of investigation is passing the sound processing from a software in a computer inside the classroom to a website and being able to connect to it several smart objects besides the mats, with the web becoming part of the Internet of Things as investigated in Santos (2023).

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