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A TAXONOMY OF MUSICAL INTERFACES FOR USE IN THE CLASSROOM

TAXONOMÍA DE INTERFACES MUSICALES PARA SU USO EN EL AULA

Emma Wilde*
Mario Alberto Duarte-García*

Correos electrónicos: emmawildecomposer@gmail.com
mduarte@enesmorelia.unam.mx

* Escuela Nacional de Estudios Superiores, Unidad Morelia; Universidad Nacional Autónoma de México UNAM.

RESUMEN:

Las taxonomías de los instrumentos han sido una preocupación a lo largo de la historia. Sin embargo, las interfaces musicales que involucran el uso de algún mecanismo digital sonoro (para traducir datos que genera un usuario a través de la sonificación y generar un resultado sonoro) no encajan en las taxonomías tradicionales. Magnuson (2017) argumenta que es necesario determinar una clasificación sobre los principios de las interfaces musicales. Esto debido a que, una taxonomía de este tipo ofrece beneficios claros a los productores, intérpretes, musicólogos y compositores. Los autores de esta investigación proponen que los docentes también son un grupo que puede beneficiarse de una taxonomía que clasifique el uso educativo de las interfaces musicales. Diversos investigadores han argumentado que existe la necesidad para evaluar el porqué y el cómo (objetivo y metodología) esta tecnología ha sido implementada en las aulas (Himonides, 2018). Existen taxonomías de interfaces musicales; no obstante, dichas taxonomías se han enfocado mayoritariamente en la clasificación del diseño e interacción del usuario y parcialmente (sin profundizar) en el campo educativo. En este artículo se muestra la taxonomía que profundiza en el ámbito educativo y se somete al análisis de 4 casos internacionales en un contexto pedagógico. Los autores muestran el uso de dicha taxonomía para clasificar el cómo y el porqué (objetivo y metodología) de su implementación en el aula y además se analizan los beneficios educativos de que esta taxonomía puede promover.

Palabras claves: taxonomía de instrumentos musicales digitales, pedagogía de la tecnología musical, interfaces musicales, educación musical, tecnología musical en el aula.

ABSTRACT:

Instrument taxonomies have been a preoccupation throughout history. Musical interfaces which involve the use of a sound engine (which could be a software) to sonify and translate data from a user to produce a sound result, do not fit into traditional instrument taxonomies. Magnusson (2017) argues that it is necessary to determine classification principles of musical interfaces because there are clear benefits of such a taxonomy for inventors, performers, musicologists, and composers. We propose that educators are another group of people who can benefit from a taxonomy of musical interfaces which considers classifications relating to educational use. Several researchers have argued that there is a need to evaluate how and why technology is implemented in the music classroom (Himonides, 2018). Previous taxonomies of musical interfaces have focused on design principals and user interaction and have only partially explored educational objectives. In this paper we propose a taxonomy of musical interfaces which builds on previous taxonomies but extends them into the educational field. Throughout four case studies of recent musical interfaces implemented in educational contexts in four continents, we show how this taxonomy can be employed to classify how and why a musical interface is implemented in the classroom to analyze the educational benefits they can promote.

Keywords: digital musical instruments taxonomy, music technology pedagogy, musical interfaces, music education, music technology in the classroom.

1. Introduction

During the last twenty years, there has been an increasing interest in the design and creation of musical interfaces for educational use. Pessoa et. al (2020) compiled a catalogue of digital musical instruments presented at the New Interfaces for Musical Expression Conference from 2001 to 2019 and found that during these years there was an increasing number of musical interfaces presented at the conference that were designed specifically to be used in educational contexts or had potential to be used in such settings. As more musical interfaces are being created for educational purposes, a taxonomy of these devices which includes classifications relating to educational objectives and purposes will be useful for educators who are looking for a framework to understand how and why such tools are being implemented in the classroom.

Himonides and Purves (2010) argue that there is a lack of critical evaluation of the use of technology in the music classroom and propose that there is a need to evaluate how these tools are employed, for which purposes they are used and which learning principles are being assessed when these tools are implemented in the educational context. Himonides (2018) suggests that there is a need to explore why technology is being employed in the classroom and how can it be used effectively.

This paper proposes a taxonomy that takes ideas from previous taxonomies of musical interfaces as a starting point and expands them to include an educational purpose and use taxonomy that can be employed to classify how and why a musical interface is implemented in an educational context.

In the proposed taxonomy we will use the term musical interface instead of musical instrument or digital musical instrument. The difference between a musical instrument and a musical interface is that an instrument produces sound directly by the intervention of the user whereas an interface collects data from the user and requires a sound engine (which could be a software) to translate and sonify the data to produce a sound result. The term musical interface therefore is a more adequate description of the recent devices being created for use in the classroom which require sound engines, and not only a user, to produce the sonic result.

2. Pre-Existing Taxonomies of Musical Interfaces

The attempt to classify musical instruments has been a preoccupation throughout history. During the 20th century, the Hornbostal-Sachs taxonomy created in 1914 emerged as the most popular method of classifying instruments. This taxonomy divides the instruments into four groups according to the way in which sound is initialized: idiophones (where the instrument itself initiates the sound without the need for strings or stretched membranes), membranophones (where the sound is initiated by “tightly stretched membranes”) chordophones (where “one or more strings are stretched between fixed points") and aerophones (where "the air itself is the vibrator in the primary sense") (von Hornbostel, Sachs, 1961). The Hornbostal-Sachs classification has been described as a hierarchal structure or top-down approach which firstly classifies the instruments in four broad categories and later develops smaller levels of classification which detail the exact ways in which the instruments produce sound (Magnusson, 2017).

In 1940, Sachs proposed an additional fifth category of electrophones which proved to be sufficient to classify the electronic instruments of the time. Various authors have argued that Sach´s electrophone category no longer adequately serves for the classification of the wide variety of new musical interfaces that are available in the twenty-first century and therefore there have been attempts to revise the category. Birley and Myers (2015) have described the changes made to the taxonomy by the MIMO (Musical Instruments Museums Online) consortium in 2011 in which the electrophone category was revised and subdivided into the following subcategories: electroacoustic instruments and devices, electromechanical and analogue electronic instruments, modules, and components. Weisser and Quanten (2011) argued that various characteristics of digital instruments, such as their hybridity and construction with various components, means that they do not fit into the Hornbostal-Sachs model and suggested revisions to the taxonomy to include instruments with timbral modifiers. Due to the diversity and ever-changing nature of new musical interfaces, the top-down approach to instrument classification present in taxonomies like those based on the Hornsbostal-Sachs model has been criticized by Magnusson who describes it as an incoherent way of classifying digital instruments (2017).

In the twenty-first century various proposals of taxonomies of musical interfaces have been made. Miranda and Manderley (2006) have provided an overview of new digital instruments which focusses on sonification models, sensor types, and gestural controls and how the user interacts with the interface in tactile or intangible ways with an emphasis on the design of the device. Paine (2010) produced a taxonomy based on the results of a questionnaire which examined the practice and application of new interfaces for real-time electronic music performance. The questionnaire contained 72 questions relating to six categories: general description, design objectives, physical design, parameter space, performance practice and classification. Based on the results of the survey, Paine proposed the beginnings of a taxonomy which takes three categories as a starting point: gesture (how the user interacts with the device in tactile or intangible ways), digital controller, and software (Paine, 2010).

More recently, Magnusson (2017) has signaled the need for a classification of new musical interfaces which considers a variety of viewpoints, including cultural areas, musical style, and other areas and proposes an approach which abandons the hierarchical systems of previous taxonomies. Magnusson (2017) argues that it is necessary to determine classification principles of new musical interfaces because there are clear benefits of such a taxonomy for inventors, performers, musicologists, and composers. We propose that educators are another group of people who can benefit from a taxonomy which contains categorizations relating to educational purposes and objectives of musical interfaces.

The recent taxonomies of musical interfaces tend to focus on design principles, physical features, and user interactivity and not on the pedagogical uses and objectives of such devices. However, Pessoa et. al (2020) have proposed a taxonomy of digital musical instruments which contains categories relating to educational use. This taxonomy contains categories that correspond to physical design features and user interactivity: interactors (how many performers/computers are involved in the system), input controller (which refers to how the user interacts with the interface), typology (whether the device is score or performance driven). These categories are complemented by further classifications that link to educational purposes such as: required expertise (if the interface is meant for novices or experts), learning curve (elementary or advance), and degrees of educational affiliation (if the device is intended for educational use or has potential to be used in such a way) (Pessoa et. al, 2020).

The educational use categories proposed by Pessoa et. al (2020) are somewhat limited as they do not explore specific pedagogical objectives and uses. Revision and expansion of these educational categories is necessary to be able to classify in more detail the ways in which musical interfaces are implemented in the classroom and for what musical educational objectives.

3. A Taxonomy of Musical Interfaces for Use in the Classroom

The proposed taxonomy includes four different categories of classification: design and function, sonification models, performance models and educational objectives and purposes (Figure 1).

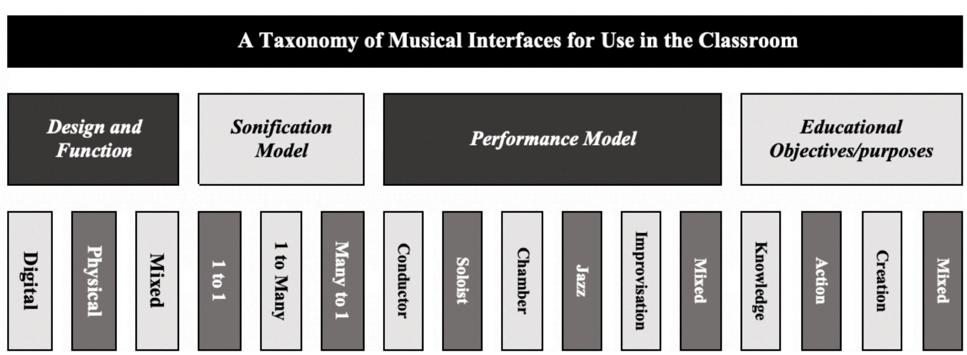

Figure 1. Overview of the Taxonomy of Musical Interfaces for Use in the Classroom.

3.1 DESIGN AND FUNCTION

The first classification category of design and function aims to summarize the different ways in which the user primarily interacts with the interface. This classification revises and extends the category of "input controller" in the taxonomy proposed by Pessoa et. al (2020), which describes ways in which the user interacts and inputs information into the interface to detonate a response. The design and function classification divides in to three categories: digital primary interaction, physical primary interaction, and mixed (Figure 2).

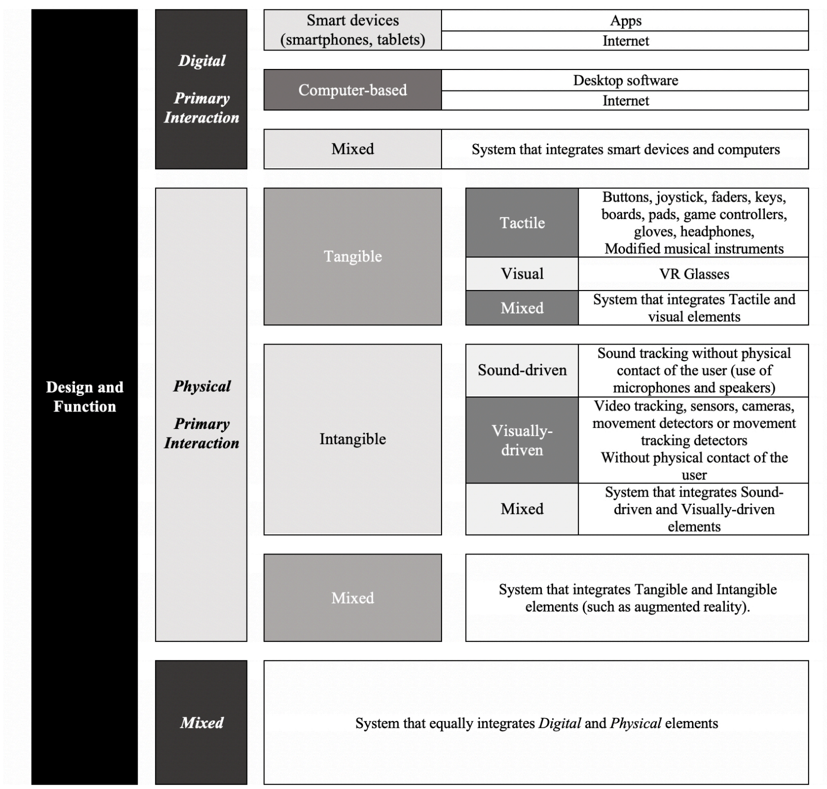

Figure 2. Design and Function classifications.

Digital Primary Interaction

The digital primary interaction category contains three subcategories: smart devices, computer-based and mixed.

- *Smart devices*:

The category of smart devices refers to small, portable gadgets such as smart phones and tablets and refers to the user having to interact with applications and internet software through the handheld device.

• *Computer-based*

Computer-based means that the user will need to access desktop or internet software on a laptop or desktop computer to be able to interact with the system. There are examples of musical interfaces for educational use which only use computer-based software, such as EARS2 (Landy et al, 2013).

• *Mixed*

The mixed category refers to an interface which requires an equal interaction between smart devices and desktop/laptop computers.

Physical Primary Interaction

The physical primary interaction category divides into the following subsections: tangible, intangible and mixed.

• *Tangible*

Tangible refers to the need for the user to make physical contact with the interface. The tangible category divides into tactile, visual, and mixed subcategories. Tactile refers to interaction through buttons, joysticks, faders, keys, boards, pads, gloves, headphones or modified musical instruments which the user interacts with manually. Visual refers to the use of VR glasses. Mixed corresponds to a system in which the user interaction is throughout a combination of tactile and visual elements.

• *Intangible*

Intangible means that no physical contact between the user and the interface is required. The intangible category divides into the subsections: sound-driven, visually-driven and mixed. Sound-driven means that there is a sound tracking device which does not require physical interaction with the user, for instance, that there is a microphone or sensors which capture sound produced by a user without the need for physical contact. Visually/movement-driven refers to the implementation of detectors which identify, from a distance, visual information, or gestural movements from the user. This can include video tracking sensors, webcams, Kinect, Arduino, cameras, movement sensors, infrared sensors, proximity sensors, amongst others.

• *Mixed*

Mixed denotes a system that integrates tangible and intangible elements.

Mixed

A system which requires equal interaction between digital and physical elements.

3.2 SONIFICATION MODEL

The sonification model explains how the data which is inputted into the device is linked to a sonic parameter (Walker & Ness, 2011). This category contains three models of sonification described by Miranda and Wanderley (2006). The one-to-one model means that one piece of data is linked to one sonic parameter. The one-to-many model signals that one piece of data is linked to many aspects of sound. The many-to-one model indicates that several sources of data are linked to one sonic outcome (Figure 3).

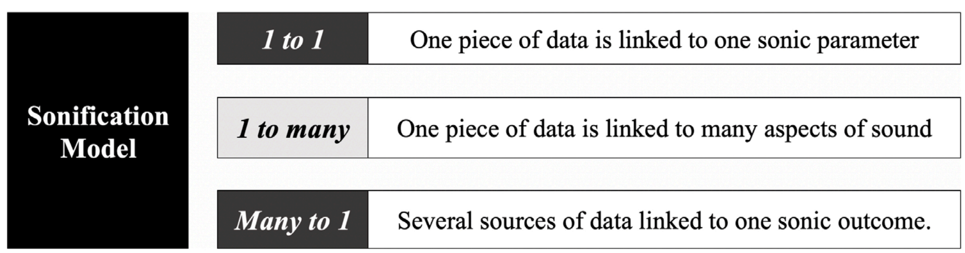

Figure 3. Models of sonification.

3.3 PERFORMANCE MODEL

The performance model is extrapolated from a model proposed by Winkler (2001) which defines the different relationships between computers and performers in mixed media music. Winkler´s model can also be a useful way of categorizing the performance relationships which occur when a user or various users/performers engage with the interactive system. The performance model contains five subcategories: conductor model, soloist model, chamber music model, jazz model and free improvisation model (Figure 4).

Performance Model	***Conductor Model***	Linear structure. One performer/computer is responsible for triggering sonic events within an ensemble context.
	Soloist Model	Linear structure. One performer/computer triggers sonic events.
	Chamber Music Model	Linear structure. Several performers/computers reciprocally influence the outcome of sonic events.
	Jazz Model	Linear structure that permits elements of a non-linear structure. Performers/computers interact or improvise within a previously conceived structural/conceptual framework.
	Free Improvisation Model	Open form/non-linear structure where no member of the ensemble is in complete control of the sonic outcome.
	Mixed	A blend of *Conductor Model* and/or *Soloist Model* and/or *Chamber Model* and/or Jazz Model and/or *Free Improvisation Model*

Figure 4. Performance Model.

Conductor Model

Within an ensemble context, one computer/performer is responsible for triggering sonic events within a linear structure.

Soloist Model

One performer/computer triggers sonic events within a linear structure.

Chamber Music Model

Several performers/computers reciprocally influence the outcome of sonic events within a linear structure.

Jazz Model

Several performers/computers interact and improvise within a previously conceived structural or conceptual framework within a linear structure that can contain elements of a non-linear structure.

Free Improvisation Model

No member of the ensemble (performer or computer) is in complete control of the sonic outcome within a non-linear or open form structure.

3.4 EDUCATIONAL PURPOSES/OBJECTIVES

To describe and categorize the ways in which interactive systems can be employed within an educational environment for the purpose of learning musical concepts, we devised three subcategories of educational objectives based on constructivist theories proposed by Díaz-Barriga & Hernández (2010) and Pimienta (2007) which we blended with ideas taken from the taxonomy of educational objectives developed by Bloom et. al (1956). Figure 5 displays these categorizations.

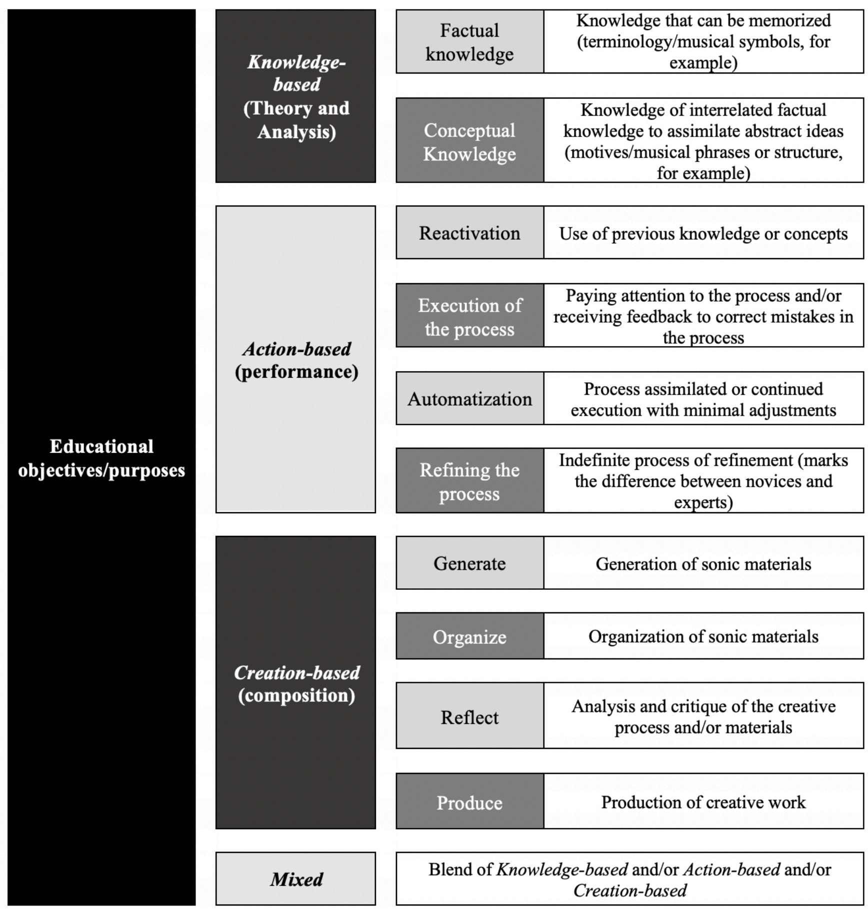

Figure 5. Taxonomy of educational purposes/objectives.

Knowledge-based

The category of knowledge-based objectives ties to the learning of data, facts, and principles. Within the camp of music education this can relate to the area of music theory, notation, and analysis. Within this category we find two subcategories: factual knowledge and conceptual knowledge.

• *Factual knowledge*

Factual knowledge is data or facts that can be memorized (for example musical terminology and notation). Students need to acquire this kind of knowledge to understand concepts that will take them to higher levels of abstract thinking.

• *Conceptual knowledge*

Conceptual knowledge refers to a more complex process in which the student interrelates factual knowledge to assimilate abstract ideas, principles, theories, models or concepts relating to a particular topic, subject or field (for instance, musical structures, phrases, and development of musical motifs).

Action-based

Action-based refers to a procedural knowledge that can be associated with musical performance. This relates to the execution of a procedure in which the student needs to use previously acquired factual and conceptual knowledge to be able to complete a task. This category subdivides into four sections: reactivation, execution of the process, automatization and refining the process.

• *Reactivation*

Reactivation is when the student retrieves previously acquired knowledge which they will need to be able to complete or perform a task. Reactivation can be employed in the classroom thorough short questionaries, exercises, tests, or small activities/tasks carried out at the start of the lesson before the main activity.

• *Execution of the process*

Execution of the process is when the student pays attention to the development of the process and may receive feedback to be able to correct their mistakes. This culminates with the realization of the task.

• *Automatization*

Automatization refers to when the student assimilates the process and can continually carry it out without the need for intervention or major adjustments.

• *Refining the process*

Refining the process is the indefinite procedure of enhancing the realization of the task. During this stage the student continues to master a technique or a task. This phase marks the difference between novices and experts.

Creation-based

Creation-based relates to learning objectives tied to composition. These learning objectives are experienced based and centered in personal aesthetic judgements. This category divides into four subcategories: generate, organize, reflect, and produce.

- *Generate*

  Generate refers to the generation of sonic materials. This cognitive process could be accomplished through improvisation (to generate materials), composing, and collecting ideas or sonic samples, etc.

- *Organize*

  Organize denotes the organization of sonic materials. The student employs a way to organize materials, for example by using a set of rules, a structure, a methodology or a narrative.

- *Reflect*

  Reflect is when the student analyzes or critiques the creative process, or the sonic materials and structures generated. The student receives feedback (through their own reflection or from a peer or teacher), the process is complete when a change/correction is produced in the task, activity, or sonic outcome.

- *Produce*

  Produce refers to the production of the creative work. This stage is the higher cognitive level, previous processes have been completed, and the student produces an outcome (which is original, unique).

4. Case Studies

To display how the proposed taxonomy can be used to classify and describe musical interfaces which are used for educational purposes, we present four case studies analyzed by the proposed taxonomy. We have decided to present case studies of musical interfaces used in countries in four different continents (North America, Australasia, Africa, Europe) to provide a global overview of recent musical interfaces developed for educational use. The musical interfaces were employed in educational projects carried out between 2008-2020. These cases were selected because all the interfaces were used for specific educational purposes and the authors in each case have explained in sufficient detail how and why the interfaces were implemented in an educational context. Additionally, the case studies were selected to show a range of designs and functions, performance models and educational objectives and purposes.

4.1 Case Study 1: Mexico

This first case study describes a musical interface designed and implemented by the authors in educational workshops which took place in a primary and secondary school in the rural community of Tumbisca in Michoacán, Mexico during 2018 to 2020. In rural areas in Mexico there is a lack of access to music technology education and the project was devised to start to respond to this problem (Duarte and Wilde, 2021).

The community of Tumbisca has limited resources and facilities. In the schools, there is no access to the internet throughout modems, there is intermittent power and there is no access to computers or tablets, therefore we had to devise a musical interface that would function despite these limitations. We realized that many students had access to smart phones and data from a mobile company. We took advantage of this fact to develop an interactive music system that comprises an app for android devices. The app contains a graphical user interface throughout which the user can move faders and select buttons to trigger prerecorded sounds and process them through sonic manipulations such as pitch shifters. A connection is established throughout the graphical user interface and a laptop computer which runs MaxMSP software which means that the user is controlling the MaxMSP software through the graphical user interface on the smart phone device. The app was used to support the teaching of musical parameters (such as duration, intensity, space, timbre and pitch) and to enable the creation of musical compositions.

Design and Function – Digital Smart Devices

The primary user interaction is throughout an android app on a smart phone device, which relates to the smart devices subcategory of the digital primary interaction classification.

Sonification Model – One to one

The musical interface employs a one-to-one model of sonification. For example, one fader or button in the graphical user interface is linked to one sonic parameter (such as duration, pitch, timbre or intensity) or one sonic manipulation (such as pitch shift).

Performance Model - Mixed (Conductor model blended with jazz model)

A performance model employed in the workshops contained a blend of elements of the conductor model with the jazz model. During the workshops the students created a fixed structure of a composition, for example a ternary structure (ABA). One student then used the app in the smart phone to trigger a prerecorded sound which signaled the start of a section of improvisation within the preconceived structure. The other members of the ensemble would then improvise with acoustic instruments or sound producing objects, aiming to echo and respond to the sound triggered by the student with the app. One student used the app to signal the start of the improvisation sections which exemplifies the conductor model, where one performer/computer is responsible for triggering sonic events within an ensemble context. On the other hand, as the students were improvising within a previously conceived structure, characteristics of the jazz model were also present.

Educational objectives/purposes – Mixed: Blend of knowledge-based, action-based, and creation-based

The music education workshops were divided into four stages: understanding sounds, playing with sounds, organizing sounds and sound in action.

- *Understanding sounds – knowledge-based*

In the first stage, understanding sounds, the concepts of the musical parameters (duration, intensity, space, timbre and pitch) were introduced, and the musical interface was used to exemplify these parameters. In this stage the educational objective of the interface was knowledge-based as it was used so that the students could acquire factual knowledge (knowledge that can be memorized – in this case the definitions of the musical parameters).

- *Playing with sounds – action-based/creation-based*

During the second stage, playing with sounds, the students were encouraged to improvise with the interface and trigger sounds and manipulate them to enable the reactivation of the previously acquired knowledge of the musical parameters. Reactivation of previously learnt knowledge is a subcategory in the action-based classification of the educational objectives/purposes taxonomy.

- *Organizing sounds – creation-based*

In the third stage, organizing sounds, the students began to reflect on the sounds they were triggering, and they began to think of how they could organize the sounds they were creating into a musical structure. Reflecting and organizing are subcategories of the creation-based classification in the taxonomy.

- *Sound in action – action-based*

In the final stage, sound in action, the students used the app as part of a performing ensemble and at the end of a project a concert was realized in which the students performed the compositions they had conceived. The students created a fixed structure of a composition, for example a ternary structure (ABA). Within the ensemble, one student used the app in the smart phone to trigger a prerecorded sound which signaled the start of a section of improvisation within the preconceived compositional structures the students created in the prior phase. The other members of the ensemble would then improvise with acoustic instruments or sound producing objects, aiming to echo and respond to the sound triggered by the student with the app. During the rehearsals of the ensemble, the students had to pay attention to the process and listen to when the student with the interface (the conductor) triggered the sounds to initialize sections of improvisation. This aspect of paying attention to the process relates to the execution of the process which is a subcategory of the action-based category of the taxonomy. During rehearsals the students assimilated the process of improvising within the preconceived musical structure without the need for major adjustments which exemplifies the automatization subcategory of the action-based classification.

During the different stages of the workshops the interface was used for different educational purposes and objectives, firstly the objective was knowledge-based as the aim was to acquire knowledge of the musical parameters, then the objective became action-based and creation-based as the students began to use the interface to reactivate knowledge of the previously learned concepts and to reflect and organize sounds into a musical structure to create a composition. Finally, in the last stage, the objective was action-based as the students had to pay attention to the process of performing the compositions created within an ensemble context.

4.2 Case Study 2: New Zealand

The project entitled "Music Education using Augmented Reality with a Head Mounted Display" was developed in New Zealand in 2013 with the "aim of exploring the use of augmented reality to improve the efficiency of learning of beginner piano students" and to encourage "notation literacy, motivation and interest" (Chow et. al, 2013, 73). The musical interface comprises an augmented reality head mounted display, a camera, an electronic keyboard, and a desktop computer.

The student sits at the electronic keyboard wearing the head mounted AR device. In the design of the interface, inspiration was taken from the model of karaoke videos where text and music are synchronized using visual cues (Chow et. al, 2013). In the system, the notes of the piano piece the student is learning appear in the AR view as a line above the corresponding piano key on the electronic keyboard alongside a score-following feature in which the student can view the corresponding musical notation.

The length of the line in the AR view represents the duration of the note and when the end of this line reaches the electronic keyboard, the student should release the piano key, developing understanding of rhythmic and pitch notation. The virtual notes are loaded from a stored MIDI file of the piece the student is learning which becomes the reference for judging the accuracy of the students playing.

During the interaction with the musical interface the student receives real-time feedback about the accuracy of their playing (their pitch, timing, and dynamics) in that the lines in the AR view change color according to accuracy (with red lines indicating inaccuracy and green lines corresponding to good accuracy). When the student finishes playing, they receive a summary of their accuracy in percentages in the AR view (Chow, et. al 2013).

Design and Function: Physical Mixed

The musical interface exemplifies the physical mixed classification of the design and function category. The user interacts with the interface through a combination of tangible and intangible elements. A tangible, tactile element is the electronic keyboard and the AR head mounted display is a tangible, visual element. There is also a camera which compiles information about the user´s movements which is an example of a visually driven, intangible element of the user interaction with the interface.

Sonification: One to many

Each time a key on the electronic keyboard is pressed, a digital signal containing information about the way the note is pressed is sent to the computer which includes information about the pitch and velocity (dynamics) of the note. This means that one piece of data (the pressing of the key on the electronic keyboard) is linked to many aspects of sound (pitch and dynamics) exemplifying the one-to-many sonification model.

Performance Model: Soloist

The musical interface exemplifies the soloist performance model as one performer or computer is responsible for triggering the sonic events within a linear structure. Chow et. al (2013) state that the MIDI file which is preloaded into the system contains timings for each note, which are strictly enforced by the system, which means that one computer is responsible for triggering the sonic events. On the other hand, the student can change the tempo of this MIDI file before beginning the exercise, but still the soloist performance model is in play in this case as only one performer is responsible for triggering sonic events.

Educational objectives/purposes: Action-based (performance)

The educational objectives and purposes of the musical interface correspond to the action-based classification of the taxonomy which links to performance-based musical education objectives. Chow et. al (2013, }73) state that the educational objective of the musical interface is to "improve the efficiency of learning of beginner piano students of beginner piano students" and their notation literacy, arguing that many piano students only receive an hour of guided instruction per week and the rest of the time they practice alone, often forgetting the concepts learned in their weekly lessons with a teacher. Therefore, one of the aims of the musical interface is to reactivate previously acquired factual knowledge (musical notation), which was acquired during guided lessons with the students´ piano teachers. This educational objective of the musical interface corresponds to the first category of reactivation in the classification of action-based education objectives in the educational objectives/purposes section of the taxonomy.

Chow et. al (2013) emphasize the importance of the feedback features of the musical interface. In synchronous lessons when the students interact with the musical interface the students receive real-time feedback about the accuracy of their playing (their pitch, timing, and dynamics) when the lines in the AR view change colors. Red lines indicate inaccuracy (a missed note), and green lines correspond to good accuracy. When the student finishes playing, they receive a summary of their accuracy in the form of percentages in the AR view. This feature of the interface relates to the subcategory of execution of the process which refers to when a student pays attention to the process and receives feedback to correct mistakes in the process.

4.3 Case Study 3: Africa/North America

The project entitled "e-piano" was carried out during 2008-2009 between a teacher located in North America and two students aged 8 and 10 living in rural Zambia, Africa with the educational aim of teaching piano performance online in synchronous and asynchronous modalities. The project was designed to mitigate the technological problems that can arise when implementing distance learning between two geographically disparate locations (Shoemaker and van Stam, 2010).

The musical interface comprised an online software called Internet MIDI, which "enables two piano keyboards to control, synchronize, and exchange data electronically through MIDI technology" (Shoemaker and van Stam, 2010, abstract, para. 3). Internet MIDI enables communication between two electronic keyboards as "musical data is sent out electronically over the Internet in real-time, so that a piano key that is played on one keyboard will sound the same key on the remote partner keyboards" (Shoemaker and van Stam, 2010). The software also has a visual feature in that it contains an animated keyboard whose notes light up on the computer screen as the teacher plays to the students or vice-versa (Shoemaker and van Stam, 2010).

The software Internet MIDI was used in real time during synchronous classes to enable better communication between the teacher and students during video conferencing. The software Internet MIDI was also used by the teacher to record videos on the animated piano keyboard that could be uploaded online as material for asynchronous study (Shoemaker and van Stam, 2010).

Design and Function: Mixed

The user interaction in *epiano* falls into the mixed category as the primary interaction is throughout an equal share of digital and physical elements. The digital elements correspond to computer-based elements as the interface comprises two desktop computers (one for the teacher, and one for the students) which employ the internet-based software Internet MIDI through which the students and teacher can see the keys of an animated piano light up in response to what they are playing. The physical elements are the two electronic keyboards which exemplify tangible, tactile means of user interaction.

Sonification: One to many

Each time a key on one of the electronic keyboards is pressed, information about the note and the way the note is pressed is sent to the computer which includes information about the pitch and velocity (dynamics) of the note and triggers a visual response in the internet software. This means that one piece of data (the pressing of the key on the electronic keyboard) is linked to many aspects of sound exemplifying the one-to-many sonification model.

Performance Model: Chamber Music Model

The software Internet MIDI allows for communication between various performers/computers, in this specific case the two students in Zambia and the teacher in North America, although Shoemaker and van Stam (2010) point out that the interface can be used in group lessons between various amounts of students. The two-way communication provided by the software means that several performers/computers can reciprocally influence the outcome of sonic events within a linear structure, which exemplifies the chamber music model of the performance model taxonomy.

Educational objectives/purposes: Mixed – blend of Knowledge-based (theory and analysis) and Action-based (performance)

The educational purposes of the musical interface *epiano* relate to both knowledge-based and action-based objectives, displaying a mixed classification of educational objectives. During a synchronous online lesson, it became apparent that one student had misunderstood concepts relating to the reading of musical notation. Due to problems of internet connection, it was difficult for the teacher to explain the concepts in real time. As an alternative, the teacher created videos using the animated piano in the Internet MIDI software to explain the concepts and uploaded the videos online for the student to study in their own time asynchronously (Shoemaker and van Stam, 2010). This usage of the interface relates to the category of factual knowledge (knowledge that can be memorized such as musical notation) which falls in the knowledge-based classification of educational objectives/purposes.

The use of the interface in real-time lessons corresponds to the action-based classification which relates to performance-based learning objectives. During real-time communication through Internet MIDI, "the teacher has been able to give feedback in order to reinforce concepts, and to nurture proficiency in technique, performing, music-reading, and critical listening" (Shoemaker and van Stam, 2010, Benefits section, para. 1). The reinforcement of concepts corresponds to the reactivation subcategory of the action-based educational objectives classification. The aspect of receiving feedback to be able to improve in the performance of the task corresponds to the execution of the process subcategory of the action-based classification. The nurturing of critical listening skills also corresponds to the execution of the process as the development of listening skills relates to paying attention to the process.

4.4 Case Study 4: Greece

In this project, the musical interface called *Gestus* was used to teach soundscape composition during a five-day workshop with 32 children (aged between 5 and 16 years). The *Gestus* interface contains a semi-transparent table-top like surface upon which the user can place and move objects which show fiducial shapes that have been assigned previously recorded sonic materials. An infrared camera retrieves the information about the user´s movements and sends the information throughout an OSC protocol to sonify the movements throughout the use of Supercollider. The user´s physical movements and gestures affect the sonic outcomes. In the workshop, the participants´ previously recorded elements of natural soundscapes were modified with feature extraction methods and assigned to the fiducial shapes in the objects placed on the interface so that the participants could explore sonic textures and create soundscape compositions (Kantouras and Zannos, 2017).

Design and Function: Physical Mixed

The musical interface exemplifies the category of physical mixed as the primary interaction with the user is throughout the tangible, tactile element of the objects placed on the semi-transparent surface of the interface. The interface also includes an intangible visually driven element in the form of the infrared camera. The user does not physically interact with the infrared camera, but the camera is retrieving information about the user´s movements to be able to sonify them.

Sonification Model: One to many

Each fiducial marker on each object "can correspond to one sampled sound coupled with a sound processing algorithm" (Kantouras and Zannos, 2017, 338). One piece of data (the fiducial marker) is linked to various aspects of sound (the sampled sound and the sound processing algorithm).

Performance Model: Jazz Model

In the context of the workshop, the objects with fiducial markers which are placed on the *Gestus* interface are assigned sonic materials which have previously been recorded by the participants. The workshop leaders selected the most musically interesting materials to assign them to the fiducial markers. This selection and assignation of sonic material means that there is a previously conceived conceptual framework in which the participants can interact and improvise. During the workshop, several participants worked in teams to improvise and explore the sonic outcomes provoked by their gestural movements. Due to the element of improvisation in the workshop, some participants aimed to create a lineal structure in which there were points of climax for instance, whilst others maintained a freer, non-lineal structure. The characteristics of the performance model of the workshop relates to the jazz performance model which involves several performers interacting or improvising within a previously conceived framework which can incorporate features of linear or non-linear structures.

Educational objectives/purposes: Mixed: Creation-based (composition)

The *Gestus* musical interface was employed in a five-day workshop with 32 participants (aged between 5 and 16 years), who were split into four groups according to age. In the first part of the workshop the four groups were taken outside into the field during an hour-long session with the aim of recording their own sounds made from natural sources for consequent implementation in the musical interface. The participants were taken out in the field to "explore sounds made from natural sound sources and relate them to hand gestures with view to their potential of creating new sound textures" (Kantouras and Zannos, 2017, 338). The participants were encouraged to explore the relationships between physical gestures and resultant sounds (for example how scratching wood or rubbing a rock causes a certain sound result). The participants were then asked to write down when a particular gesture was causing a significant interest. Each group recorded around 25 audio samples from which the workshop leaders selected the most musically interesting samples to implement in the interface (Kantouras and Zannos, 2017).

During the first part of the workshop the students listened to the sounds of the environment which demonstrates the subcategory of reflect in the creation-based classification of the taxonomy. The students reflected on which sounds provoked interest, and had potential for creating new sound textures, demonstrating that they were analyzing the potential of the sonic materials. Through the act of selecting and recording the sounds which caught their attention, the students generated their sonic materials, which relates to the generate subcategory of the creation-based classification in the taxonomy.

In the latter part of the workshop the students interacted with the interface to experiment with the previously recorded sound samples with the aim of creating soundscape compositions. The selected samples were assigned to the fiducial markers on the physical objects which the students move on the surface of the *Gestus* interface. Kountouras and Zannos (2017) observed that many of the participants developed their own methods of interaction with the interface displaying attempts to create a musical structure, for example by reflecting on which gestures and objects created tranquil textures and which movements and objects generated points of climax in the musical structure.

The authors found that the participants responses differed according to age, with the youngest group (6-9 years) displaying a more random approach to the physical gestures, playing with the interface as they would with a toy whilst the eldest group (13-15 years) displayed a tendency to use more complex physical gestures and reflected on how these gestures affected the sonic outcomes and the musical structure (Kountouras and Zannos, 2017). Ten resultant soundscape compositions with the title Touching the Village were created during the workshop (Kountouras and Zannos, 2017).

In this part of the workshop, the students displayed evidence of analyzing how their movements of the objects impacted the sonic outcome, which relates to the reflect subcategory of the creation-based classification. Certain students also displayed an attempt to organize the sonic materials in a musical structure to produce a creative work, which links to the organize and produce subcategories of the creation-based classification. Therefore, the educational purposes of the *Gestus* interface in the context of this workshop relate to the creation-based classification (composition) and its subcategories of generate, organize, reflect, and produce.

5. Discussion

The case studies show how the proposed taxonomy can be applied to analyze and categorize different aspects of musical interfaces used in educational contexts. The case studies display that there is a diversity of interfaces being implemented in different educational environments. With previous taxonomies of musical interfaces, which focus on design principles and user interaction, some of these complex cases would have been difficult to analyze and a huge characteristic of their functionality and potential, their educational uses, and purposes, would go unnoticed.

One question that needs to be asked is why are these interfaces necessary in an educational context? What draws educators to these devices and why do some experience the need to develop and implement new musical interfaces in the music classroom? We have shown that one of the reasons for this necessity is to mitigate social disadvantage. In the Mexican case study, a new musical interface was needed to be developed to respond to disparities in access to music technology education in a rural area in which it would have been problematic to employ many pre-existing musical interfaces. A similar problem was faced in the case study in Africa/USA, where the participants faced problems when the quality of internet connection led to communication problems with videoconferencing which meant that the students´ education was negatively affected. The interface in question in the African/USA case study helped to respond to these technical problems and improved learning outcomes.

Another reason for the interest in new musical interfaces, is the need to provide novel and tactile ways of promoting involvement in the creative process and to support creation-based learning objectives which link to composition. As creation-based learning objectives are founded in personal aesthetic judgements, it can be difficult for educators to find ways of instigating the creative process in the classroom. New musical interfaces can provide an outlet in which students are initiated with the creative process. In the Greek and Mexican examples, the students used the musical interfaces to generate and organize sound materials to reflect on the creative process, and to finally produce a creative work.

Another purpose of musical interfaces which arose in the case studies was the way in which musical interfaces can be used to reactivate previously learnt concepts and to provide feedback and support with the execution of a task, especially tasks relating to performance. In the New Zealand, Mexico and Africa/USA examples, the interfaces encouraged students to reactivate previously learned factual knowledge such as definitions of music terminology and musical notation.

Another interesting feature of many of the interfaces analyzed is that their performance models promote collaborative experiences and communication between several participants. The examples from Greece, Mexico and Africa/USA all displayed ensemble performance situations. Collaborative group work is an important aspect of constructivist pedagogical theory as it promotes a variety of skills. The ways in which new musical interfaces can initiate collaborative experiences in the music classroom can be seen as a beneficial feature for educators.

Himonides (2018) has argued that there is a need to explore why technology is being employed in the classroom and how can it be used effectively. The proposed taxonomy aims to respond to this need for exploring the purposes and uses of technology in the music classroom. It is important to consider the design features and technological aspects of musical interfaces, but it is also necessary to consider their educational objectives.

This article proposes a taxonomy built on previous taxonomies of musical interfaces that extends into the educational field to highlight that these interfaces go beyond their technological features. Previous taxonomies have focused on the ergonomic features of musical interfaces and have only partially begun to deal with the educational purposes. This taxonomy tries to provide a perspective which considers a broader view of the educational potential and benefits of musical interfaces to encourage developers of new musical interfaces to consider learning outcomes and educational objectives.

6. Conclusion

In this paper we have examined the use of technology in the music classroom and have presented a taxonomy that can be used for classifying musical interfaces and their use for educational purposes. We have argued that it is important to consider why and how these interfaces are implemented in the music classroom, supporting the recommendations of Himonides (2018) who points out that this aspect of music technology in the classroom has only partially been investigated. This taxonomy combines classifications relating to design and function, sonification model, performance model and educational objectives/purposes to provide a more integral taxonomy that broadens the perspective beyond the technological features of the interfaces.

This taxonomy is based on a constructivist pedagogical approach. In the future there is potential to integrate other pedagogical theories and perspectives to broaden the category of educational objectives/purposes. In the post-pandemic period in which many educators have been forced to work in an online environment, it is also necessary to consider the implications of musical interfaces in face-to-face and virtual environments and the potential they have for responding to problems raised in online teaching. A taxonomy which considers differences between the use of musical interfaces in virtual and face-to-face contexts could be useful. We hope that the presentation of this taxonomy will promote more discussion about the purposes and uses of musical interfaces within education.

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