DESIGNING AN MUSICAL EDUCATIONAL SOFTWARE COMBINING TRADITIONAL MUSIC-PEDAGOGICAL METHODS AND EMERGING TECHNOLOGIES: THE CASE OF SYNTH4KIDS

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ABSTRACT

This paper presents the development of Synth4kids, a music educational software for music teaching-learning processes designed to be used for kids aged five to eight years. Synth4kids integrates elements from the traditional music-pedagogical methods –Dalcroze Eurhythmics, Orff Schulwerk, Kodály Method– along with features aligned with incorporating merging technologies in music education –augmented reality, use of tangible interfaces / sensors, eye-tracking processes, QR-codes implementation, and collaborative online music practices– providing new and extended ways of music-making, expression, and learning to the young ages. As a pedagogical tool, it was designed with the ultimate goal to be incorporated into musical-educational activities following a STEAM perspective, based on project-based, inquiry and cooperative learning, transdisciplinarity, as well as game-based, and authentic problem-solving experiences.

KEYWORDS

Virtual instruments in music education, STEAM education, Educational musical software design and development, Emerging technologies in music lessons.

1. INTRODUCTION

Current technological developments in recent years have transformed the ways children interact with music, shaping new and expanded musical experiences. In this emerging digital context, teachers should consider students' preferences for incorporating technology and digital media into their lessons [37]. The integration of current technologies in the music teaching-learning processes forms new educational perspectives as the current environments of constructing music experiences become increasingly digital and multimodal [24]. Using technological tools in music lessons can enhance learning motivation and offers students opportunities for in-depth engagement in various and diverse musical areas [14, 37]. A field gaining ground in the last years is the implementation of virtual instruments into music teaching-learning processes [25].

This article aims to present the design and the development of an educational musical tool for children aged five to eight, which utilizes the capabilities of current web browsers, especially web audio technology. Synth4kids consists of original instructional software, designed with orientation to music lessons, implementing elements and educational strategies from the traditional music-pedagogical methods. At the same time, it reflects the current digital context, drawing on emerging technologies –augmented reality, connection with tactile interfaces, eye-tracking, QR-codes, as well as collaborative online music practices through WebRTC. In this way, it opens new horizons for music experimentation and gives opportunities for new and

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expanded forms of music-making and learning. The ultimate aim of the Synth4kids software is to be used as an instructional tool that can be efficiently integrated into STEAM –Science, Technology, Engineering, Arts, Mathematics– educational activities following a project-based learning perspective, engaging students in collaborative, transdisciplinarity, game-based, and authentic problem-solving experiences.

2. VIRTUAL INSTRUMENTS & MUSIC EDUCATION

Appling virtual instruments in the educational process can offer extended and new multimodal ways of musical interaction, expression, and learning [33]. Their integration in music lessons constructs a pedagogical framework radically distinct from the conventional music teaching-learning practices [42] while, at the same time, can offer opportunities for STEAM scenarios development [34], as well as game-based learning [5]. Furthermore, virtual instruments allow students to engage students in informal musical activities inside and outside school, creating additional learning motivation [22, 24]. At a practical level, they can be used alternatively with acoustic instruments, leading to cost reduction for music equipment, as only a computer and built-in sensors –e.g., a web camera or gyroscope– are required [5].

Research has shown virtual instruments' positive outcomes in musical performance skills development, creativity enhancement [34], as well as the in-depth and meaningful acquisition of musical knowledge [14]. Primarily, visual representation of musical information and simultaneous feedback provides conditions for multimodal music teaching-learning processes [11] through the interconnection of optical stimuli –image, text, numbers, symbols– with sound [34]. Furthermore, connecting virtual instruments with sensors can contribute to multisensory experience formation through touch and movement, combined with augmented reality principles [33].

2.1. Educational virtual instruments design

Designing virtual musical instruments for pedagogical purposes should follow particular principles, considering educational software design models, technological capabilities and limitations, user experiences and needs [7, 39], as well as meet specific educational goals [22].

Although the technological improvement of the last years offers new and enhanced capabilities for digital instruments via virtual and augmented reality, connection with touch-sensitive interfaces or sensors, and compatibility with communication protocols [34], their development seems to reflect a conventional design context [31]. Current literature argues that virtual instruments' construction is based on users' experiences and behaviors with acoustic and electric instruments [41]. In this context, most of them represent existing instruments, such as pianos, glockenspiels, percussions, etc. For over two decades, it has become clear that their design should avoid the simulation of 'real' instruments and focus only on distinct elements from the users' experience [7, 39]. As no virtual instrument can offer the same experiences as an acoustic one, it is expected that their design orientation should emphasize offering possibilities for augmenting and new musical experiences [5].

The above situation also depicts the development of virtual musical instruments that are designed with orientation to be used in music lessons [24]. Emerging technologies can create conditions for meaningful multimodal learning through fruitful individual, social, and aesthetic experiences [11, 34]. Even though there are no limitations and restrictions in the design process, the current literature suggests some general guidelines. These focus on the incorporation of elements reflecting the skills and knowledge that users have from existing instruments, opportunities for multimodal feedback –visual, acoustic, tactile–, and an interaction between the real and digital worlds –augmented reality–, social interaction –collaborative performance, virtual/remote playing, hybrid orchestras–, as well as principles from the traditional music-pedagogical methods [7, 22, 24, 34, 37].

3. SYNTH4KIDS MUSICAL EDUCATIONAL SOFTWARE

Synth4kids consists of music educational software developed by the author.[1] Its design is an ongoing project that was initiated in 2018. As a virtual instrument, it was started as an analogue monophonic synthesizer representation with augmented features oriented to music teaching-learning processes. As earlier mentioned, the design's ultimate goal is to offer multimodal ways of music-making, expression, and learning through rich musical experiences and possibilities of sound experimentation and improvisation [24]. For that reason, along with the components that can be found on an analog synthesizer –sound generators, ADSR envelope, LFO, etc.– it incorporates various aspects from traditional music-pedagogical methods –chromesthesia, pentatonic scale, movable-Do technique, etc.–, as well as, elements aligned with emerging technologies in music education –augmented reality, connection with tactile interfaces, eye-tracking practices, QR-codes, and synchronous cooperative music practices.

Based on a synthesizer's virtual representation, the optical alignment of Synth4kids' features reflects how modules are placed in a conventional digital instrument (see figure 1). The content of the graphic user interface is arranged into three columns. The first contains the sound generators, the octave options, and the import and export functions –saving and loading patches. In the second column, the main screen is placed, which displays the parameters of each software module. When the user selects a component (e.g., ADSR envelope, filter, or drum-machine), the main display is adapted and presents the appropriate parameters. Below there are six diverse ready-made patches (pre-sets). The third column includes the audio output options –amplitude, panning–, pentatonic and after touch mode, the use of effects, the reproduction of –melodic/rhythmic– musical patterns, as well as the additional available options (e.g., eye-tracking, painting, face recognition) for providing expanded musical possibilities. At the bottom of the application is the music keyboard, along with some essential performance features –pitch bend, slide, and hold notes functions– common for almost every synth [22]. Finally, the keyboard can be transformed into a musical ribbon. The absence of knobs and buttons in ribbon mode gives more freedom to music playing, especially when the software is used on devices with touch screens.

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[1] Synth4kids is accessible at: www.yannismygdanis.com/synth4kids/

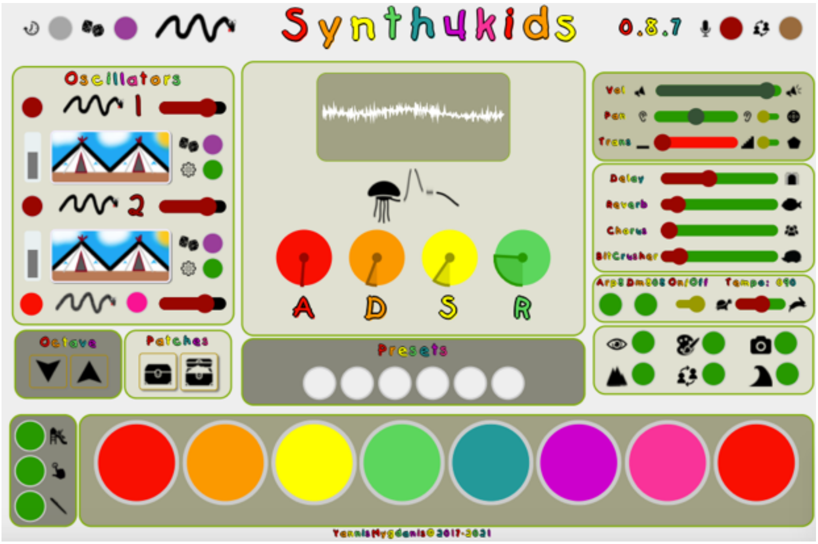

Figure 1. Synth4kids main screen

Referring to technical specifications, Synth4kids was developed entirely in HTML 5, CSS, and JavaScript programming languages, making it compatible with most web browsers [36]. For producing the sound result, the Tonejs was used, a JavaScript library created to enhance interactive online music applications development [21]. Concerning the graphic interface, the widgets –buttons, keyboards, panels, and potentiometers– were included in the NexusUI library that has been used for graphical environment development in numerous web-audio applications [36]. Furthermore, Synth4kids utilizes numerous free and open-source JavaScript libraries. A characteristic example is compatibility with the gyroscope sensor using Gyro.js library. Besides, it uses the device's web camera for face recognition with the clmtrackr.js open-source JavaScriptcode and eye-tracking utilizing the WebGazer.js library [28], as well as communication with the external Leap-Motion™ sensor via Leap-Motion™ API. Besides, the open-source P5.js library was imported for painting and drawing canvas.

3.1. Practical application of Synth4kids in music lessons

The Synth4kids software has been applied to children aged six and over in various learning environments. Below are some remarkable examples from practical interventions whose results have been published and extended to current literature. In conservatoire education, it has been used in "Theory of Music" courses through the practical application of educational scenarios that reflected the philosophy of the STEAM model with constructions of musical artifacts [23]. According to the research results, the actions using Synth4kids were found to be meaningful for students, leading to the acquisition of different musical and technological skills with high levels of creativity and experimentation. At the same time, the children showed confidence in improvising and composing with their creations. In addition, regarding the musical outcomes, it seems that they led to deeper acquisition of knowledge and understanding of abstract musical concepts and terms [23]. In school music education, it has been utilized in the music lesson for 2nd-grade students to enhance musical creativity, contributing to increased participation and interest. At the same time, it became clear that the children deeply acquisition of musical concepts, such as pitch, amplitude, duration, timbre, and tempo [19].

4. SYNTH4KIDS BASIC FEATURES

As commented earlier, Synth4kids is a virtual analogue synthesizer representation [24]. In this context, it incorporates various popular elements from the synthesizers and, more generally, digital musical instruments.

4.1. Elements from synthesizers

Generally, electronic and digital musical instruments differ in the ways of sound production and music interaction from acoustic ones. Their construction consists of two different –digital or analogue– components; a sound generator that produces the audible result and a controller –e.g., a music keyboard, a ribbon, or a sensor– for handling their usage [22, 41]. Most synthesizers typically contain specific modules, including sound generators, ADSR envelopes, filters, equalizers, low-frequency oscillators, and musical effects [9].

Synth4kids is equipped with the above essential components. The ways of the interconnection between these elements are shown in figure 2. In this section, the features and capabilities of each module will be described in detail.

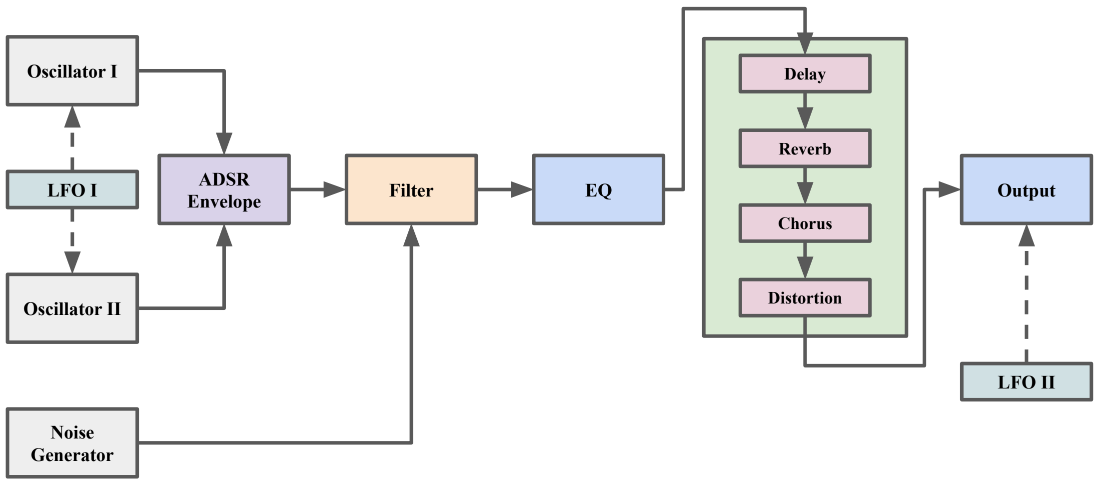

Figure 2. Synth4kids sound modules sequence

4.1.1. Oscillators

All synthesizers require at least one sound generator, which is the core of sound synthesis. Its role is to transform the signal values from a selected waveform to an audible signal [9]. The Synth4kids educational software is equipped with two oscillators that operate simultaneously, based on the four standard and typical waveforms –sine, triangular, sawtooth, and square (see figure 3). The images of the oscillators' waveforms were designed on the views of a sample of ten children aged five to seven years when asked, "what can these shapes may represent?" [21].

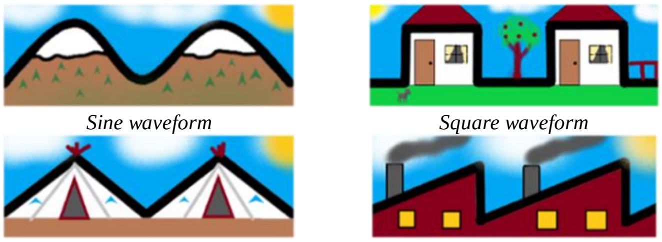

Figure 3. Synth4kids waveforms representation

Based on additive synthesis principles, the sound process results from the sum of oscillators' amplitudes. Synth4kids takes advantage of the four different types of built-in oscillators from the ToneJs library (am, fm, fat, s). Children can select a type of oscillator and a waveform to make their favorable sound patch. Alternatively, they have the possibility to experiment with sound timbre through the creation of their own complex periodic waveforms by parametrizing the amplitude value of the first sixteen harmonic frequencies (see figure 4). Besides, it is possible to choose the number of harmonic frequencies from one to sixteen.

Each sound generator provides a detune function for changing the pitch up to one octave lower or higher, a mute button, as well as a fader for adjusting the sound output volume. Furthermore, each oscillator is equipped with a random option for letting the user start from an unexpected and unknown point to create his sound design. The application also incorporates a third sound engine for noise generation, which operates in parallel with the other two sound generators (see figure 1). The student can choose one of the three typical colors of noise –pink, white, and brown– [9] or deactivate it with the mute button.

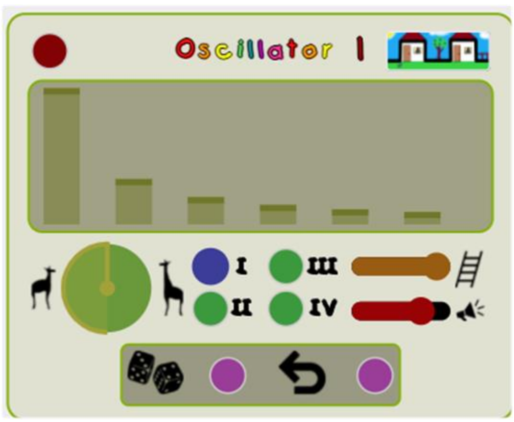

Figure 4. Synth4kids oscillator parameters

4.1.2. ADSR Envelope

ADSR envelope handles the four fundamental parameters –attack, decay, sustain, and release– of a sound, shaping its dynamic progress and formatting its unique character and timbre [9]. In the case of Synth4kids, the ADSR envelope consists of four potentiometers, one for each parameter (see figure 1). Also, the ADSR envelope is visually represented by a jellyfish tentacle, divided into four points, one for each parameter. Depending on the user's configurations, the specific part of the tentacle takes the appropriate shape, depicting the curve of the dynamic progress of the sound.

4.1.3. Filter & Equalizer (EQ)

Filters and equalizers can provide various sound deviations and shape the final amplitude by strengthening or weakening specific frequencies or frequency bands.

Filters refer to removing or emphasizing particular parts of the frequency spectrum [9]. A filter is activated at a specific cut-off frequency. The three most common are low-pass, high-pass, and band-pass filters. The Synth4kids application incorporates these filter types represented as sea waves images, depending on their shape in the audible spectrum. After enabling filter mode, the kids can change the cut-off frequency by moving a blue dot in a two-dimensional grid. The X-axis refers to the frequency, and the Y-axis to cut-off resonance (see figure 5).

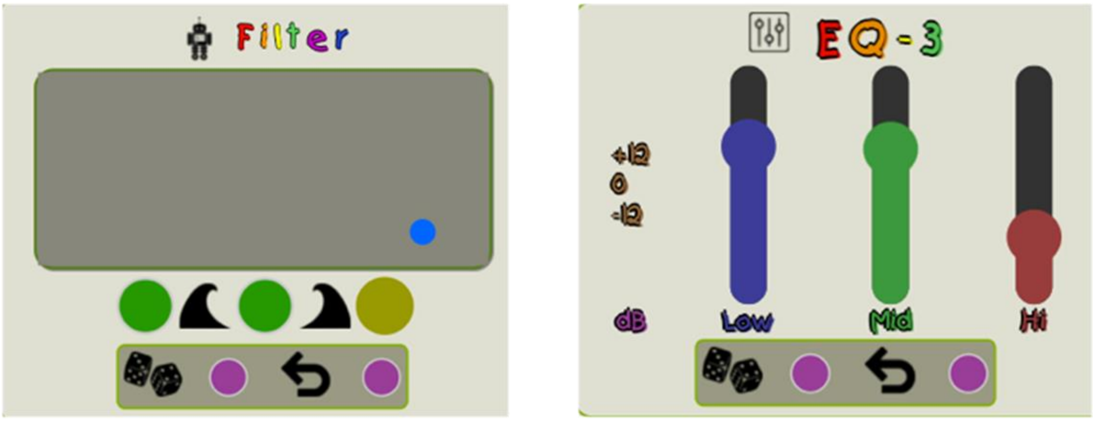

Figure 5. Synth4kids filter & equalizer

On the other hand, the role of an equalizer (EQ) is to handle the frequencies of the sound spectrum by intervening in the amplitude –increase, decrease or cut– of a specific frequency range [9]. Synth4kids includes a three-band EQ, dividing the human audible spectrum into low –20 Hz to 400 Hz–, medium –400 Hz to 2,500 Hz– and high –2,500 Hz to 20,000 Hz– frequencies (see figure 5).

4.1.4. Low-Frequency Oscillator (LFO)

A low-frequency oscillator (LFO) generates frequencies below the human audible spectrum. In this way, the waveform of an LFO can be applied to the amplitude –creating a vibrato impression– or to the frequency –giving a tremolo feeling [9]. Synth4kids is equipped with two built-in LFOs, one for the amplitude and one for frequency alternation. Both LFOs are activated through the gyroscope sensor by moving the device in space. The LFO1 is applied on the two main oscillators, while the LFO2 affects the result of the three sound generators in the last stage of the chain of the modules. The direction on the X-axis modifies the LFO1 waveform while moving on the Y-axis, the LFO2 waveform is changed. In the case the device does not enclose a gyroscope, the values of the LFO's waveforms remain constant.

4.1.5. Audio Effects

Audio effects alter audio signal processing and give a more unique sound character. The choice and sequence of applying effects determine to a decisive degree, the identity of a sound [9]. Synth4kids includes four different effects in a fixed row. Every unit is presented with an icon for assisting children in associating what they listen to with an object from the real world. In short, the delay unit, represented by a tunnel icon, replays the same signal after more than a quarter of a second. Next, the reverb module, illustrated as a puffy-fish image, shapes an imaginary space simulation. The following effect, the chorus, depicted by a choir icon, produces minimal pitch differences. Finally, the distortion effect alters the sound by greatly amplifying the signal, adding extra harmonic frequencies. As an effect, distortion is visually illustrated by the hedgehog's nails (see figure 1).

4.2. Elements from other digital instruments

The Synth4kids application also incorporates elements of electronic musical instruments that emphasize the sequencing of musical events. Representative examples are drum-machines and sequencers/arpeggiators that handle rhythmic or melodic patterns programming, respectively [9]. In Synth4kids, both the arpeggiator and the drum-machine modules can be programmed and operate in parallel with the same tempo. The overall tempo can be defined by the user on the third column of the application's main screen.

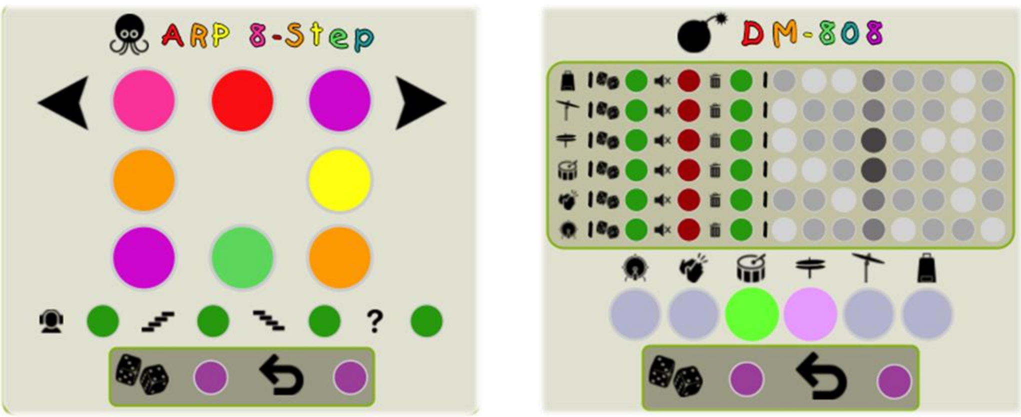

Figure 6. Synth4kids Arpeggiator & Drum-Machine

4.2.1. Arpeggiator

The role of the arpeggiator is to develop and execute melodic patterns. In Synth4kids, the user can create motives consisting of eight notes. Therefore, an octopus icon was chosen to symbolize the musical sequence. The notes are arranged in a circular-typed shape, reflecting the circularity of a loop (see figure 6). Children can create their own melodic patterns by playing notes on the musical keyboard and filling the loop. Alternatively, they can use ready-made ones constructed from the notes of a chord in ascending or descending order –depicted by a ladder icon. There is also an option for randomized creation patterns. Furthermore, the user can activate are deactivate a note of the motive by pressing the appropriate button of the sequence, giving the sense of music rest.

The arpeggiator starts the pattern execution with note C as the fundamental (tonic). At the touch of another button on the music keyboard, Synth4kids performs an automatic transposition by changing the pattern's tonic note. Transposing to another key is smooth with no disruption in the musical result. As said before, the tempo can be changed through the main display of Synth4kids. However, the user can alter the tempo at double or half by pressing the right and left arrows on the display screen. This way can provide more melodic and rhythmic interest without changing the musical pace, as abrupt doubling or changing at half the tempo gives a constant pulse impression.

4.2.2. Drum-Machine

The Synth4kids' drum-machine module is based on digital musical instruments' design philosophy for creating complex rhythmic patterns –the Roland TR808 is the most representative in this category.

Synth4kids includes six percussion sounds created synthetically through the ToneJs library –kick, claps, snare, hi-hat, crush, bell. The sound design took into account synthetic sound techniques used in analog drum-machines. The sounds are organized into a grid of six rows and eight columns. The X-axis represents the sound, and the Y-axis the eight-note values (see figure 6). Each percussion sound provides mute, random creation, and delete options. As in arpeggiator, every change on the grid is merged smoothly with no disruption in the acoustic result. Below the grid, six buttons have been added, one for each sound. When playing a rhythmic pattern, the buttons flash and show which percussive sound is heard each time. This feature was imported to provide visual feedback.

4.3. Additional features

In addition to the above, Synth4kids incorporates some features that are typical for almost all electronic musical instruments. These elements include recording, randomization, and MIDI functions.

4.3.1. Recording

During sound experimentation, it is imperative for the kid to be able to hear the audio result not only in music playing but at a later time. Generally, listening is an active process that requires focus on the phenomenon of the sound at all stages of a musical praxis [16]. To that point, when something is recorded, students can concentrate on the audible result without being distracted by technical difficulties in the performance [17]. Synth4kids is equipped with the recording function where children can record their results and save them as a .wav file to their devices. Recording takes place internally through the browser's sound output in order to ensure the best sound quality.

4.3.2. Randomization

Handling and experimenting with the parameters to produce the desired result can take much time, negatively affecting children's motivation. On the contrary, randomized selections can give opportunities for creativity and sonic experimentation [24]. The child does not need to start with the sound design from scratch or choose from random parameters and make modifications to achieve a preferred result. Taking into consideration the target age for the use of the current application, the random selection mode was integrated into Synth4kids. The random function is represented with a dice image and is observed in all software modules (drum-machine, oscillator, etc.). In addition, an overall random function is applied in all elements simultaneously, delivering more freedom and choices to start music-making.

4.3.3. MIDI functions

A characteristic feature in the majority of virtual instruments is MIDI compatibility. Synth4kids takes advantage of the Web-Midi API that is supported in modern browsers. This way, a child can control the application's parameters by connecting a midi interface or playing melodies on a midi keyboard.

5. EDUCATIONAL PERSPECTIVES IN THE DESIGN

As mentioned above, the design orientation of Synth4kids focuses on the music pedagogical perspectives and the perspectives of integrating into music lessons. On the one hand, it borrows elements from the traditional music-pedagogical methods, which have demonstrated good teaching outcomes over the years. On the other hand, it includes possibilities that give teachers opportunities for designing pedagogical actions that reflect current concepts and trends in the field of “music, pedagogy, technology” that focus on the integration of emerging technologies in music lessons.

5.1. Elements from the traditional music-pedagogical methods

Synth4kids incorporates elements drawn from the traditional music pedagogical methods – Dalcroze Eurhythmics, Orff Schulwerk, Kodály Method. In this way, it can be efficiently integrated into educational activities and applied simultaneously with conventional strategies, especially at young ages. These features emphasize chromesthesia, pentatonic scale, movable-Do technique, and kinesthetic experiences [21].

5.1.1. Chromesthesia

Chromesthesia consists of a type of synesthesia in which the sound is transformed into a color experience [3, 8]. Various charts interconnect sound with color. Synth4kids musical keyboard uses Newton’s diagram that matches the musical notes with the primary colors of the visual spectrum in a series of red to violet [22, 24]. Note C is correlated with red, D with orange, E with yellow, F with green, G with blue, A with purple, and B with violet [29]. It is worth mentioning that the same sequence of colors is widespread in music education. Representative examples are the Orff Orchestra instruments and the Boomwackers™ music tubes.

5.1.2. Pentatonic Scale

The usage of the pentatonic scale consists an integral part of Kodály’s and Orff’s methods. Kodály realized that young children had difficulties in singing the diatonic scale because of the octave range and the existence of semitones [6]. For that reason, his method commences from the vocal performance of the third minor (E-G) interval and gradually adds the pentatonic scale notes. In a different approach, Orff considered that the pentatonic scale is a native tonality and can enhance children's musical creativity [26]. Due to that, many Orff orchestra instruments – xylophones, glockenspiels, etc.– use wooden or metal bars that can be easily removed, leaving only the notes that correspond with the pentatonic scale. Synth4kids musical keyboard is equipped with the eight notes of a diatonic major scale and has the option to deactivate the fourth and seventh keys, providing a major pentatonic scale.

5.1.3. Movable-Do technique

The movable-Do technique is based on John Curwen’s tonic Sol-Fa method. The names of notes do not represent absolute pitches but the intervallic relationship between the grades of a musical scale [6]. Following the principles of the movable-Do technique, Synth4kids can transpose the pitch of the keys to a specific major scale, and the user can adjust the pitch to the preferred tonality by operating the ‘transpose’ fader. Depending on the tonic note of the selected scale, the fader changes color based on chromesthesia (e.g., yellow if the tonic is E).

5.1.4. Kinesthetic Experiences

Kinesthetic experiences are a vital part of the content of all traditional music-pedagogical methods. Dalcroze emphasizes music teaching-learning in a multisensory approach for acquiring musical knowledge experientially [16]. Kodály and Orff included elements of movement such as walking, running, or clapping for a deeper understanding of rhythmic patterns and motives [24].

Emphasis on kinesthetic functions was given during the design of Synth4kids through sensors and interconnection with tablets and laptops. As said before, LFO frequency values are alternated through the gyroscope sensor by changing the device's position in the space. Besides referring to musical keyboard and touch screen capabilities, moving the finger up, down, right, and left on each key can operate as an aftertouch function and change the pitch of the sound produced in a range of ±20Hz. Alternatively, the musical ribbon function allows more freedom for musical expression. From the above, it becomes clear that both keyboard and ribbon capabilities enable enhanced kinesthetic rare on most electronic musical keyboards.

In addition, Synth4kids can provide kinesthetic experiences by using the user's device web camera. Supporting face recognition, children can control elements such as effects, ADSR envelope, EQ, and pitch through the movement of various parts of the face –e.g., lips, eyes, eyebrows– or the movement of the whole head horizontally and vertically (see figure 7). For example, opening the mouth can affect the reverb effect, while moving eyebrows can alter cut-off frequency. The same sound parameters can also be modified by manipulating eye-tracking capabilities. Kids can choose to manage two different parameters simultaneously; one for the X-axis and one for the Y-axis (see figure 7).

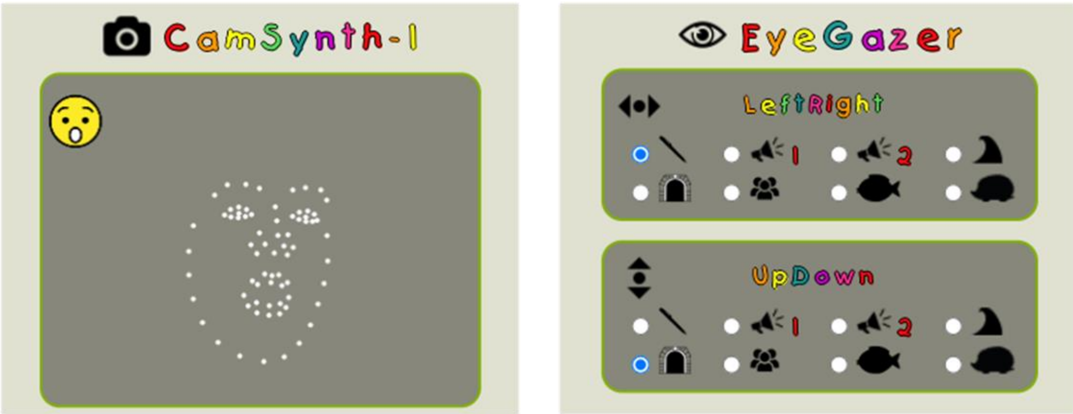

Figure 7. Face tracking & Eye-tracking function

Another fundamental feature that can provide augmented kinesthetic experiences is connecting with external devices. Synth4kids is compatible with the LeapMotion™ device, an external sensor that tracks the movement of the hands and fingers [30]. Due to its high accuracy, it can recognize the direction of the right or left hand and each finger separately. As in face recognition and eye-tracking practices, the user can set a music parameter (e.g., volume, pitch, filter, or an effect) and edit its value by moving his hands and fingers in the air.

Finally, Synth4kids is compatible with the MakeyMakey™ tactile interface. Children can create unique tangible musical instruments and artifacts by connecting conductive materials –fruit, metals, water, pencil, or the human body– in the current interface without prior knowledge circuits [22] and control all the components of Synth4kids only by touching the materials (see figure 10).

5.1.5. Collaborative practices

Collaborative practices in music teaching-learning are integral to all traditional music-pedagogical methods for students' comprehensive development –cognitive, social, emotional, kinesthetic–, motivation, critical thinking, and self-confidence enhancement. Children demonstrate a more remarkable willingness to participate in group activities than individually, especially when they present action in the classroom [16].

Synth4kids provides the ability for communication between two devices via the WebRTC protocol. Every time the application logs in, it produces a unique ID which is transformed into a QR-code (see figure 8). The importance of the use of QR-code has dual nature. On the one hand, it is an element of the modern digital context. On the other, as Synth4kids emphasizes the young ages, kids may struggle with letters and numbers. When a device shoots the QR-code, the software logs in and enables WebRTC protocol. With the 'connect' button, both browsers are interconnected. Every change in the application's parameters is transferred to the other device and vice versa by pressing the 'synchronization' button. As a result, two students can collaboratively shape a sound pre-set without being in the same device or, to a more general perspective, without being in the same space. For the latter case, the function of extracting the ID code has been taken into consideration so that it can be sent through a digital medium to a remote user.

Figure 8. WebRTC via QR-codes

The final feature that supports cooperative activities is quantization. This function can be enabled in cases of using Synth4kids in music groups, concerning orchestras made only by laptops with Synth4kids or a combination with Orff instruments. The quantization feature was made in order for two or more different devices to handle Synth4kids sequencing capabilities and play together quantized, which means performing melodic or rhythmic patterns simultaneously. Generally, it is challenging, especially for young children, to be able to perform a pattern in sync. Even if two users start the pattern execution at the same time, there may be delays in launching the web audio. For this reason, the quantization function tries to start the execution of the patterns from a fixed and standard reference point. Considering that all devices have synchronized into a specific time zone, the application quantizes the arpeggiator and drum machine to the next following second.

5.1.6. Graphic music scores

The use of graphic music scores can offer tremendous freedom of expression, creativity, and in-depth acquisition of abstract musical concepts by using symbols –images, drawings, diagrams– [35], especially for children aged four to seven years [20].

Figure 9. Drawing Function

The Synth4kids features a drawing canvas with eight colors for graphic score development. Each color is associated with a specific key of the musical keyboard. During the painting process, the application produces sound results depending on the selected parameters and the brush's position on the X-axis and Y-axis of the canvas (see figure 9). Finally, the drawing result –graphic score– can be saved as a .jpeg image on the user's devices.

5.2. Emerging technologies in music education

The conventional concepts of distribution, production, recording, and reproduction of sounds, acquire new meanings in the current digital environment. That phenomenon leads to music education transformation, and emerging technologies can play a profound role. The current literature suggests new and emerging technologies in music education, among others, ubiquitous music, augmented reality practices, and the Internet of musical things [4, 10, 18, 38].

5.2.1. Ubiquitous music

In our digital era, mobile devices, the Internet, and new ways of interacting with sound construct a new frame of music perception. Nowadays, we have access to music anytime, anywhere, from anyone at the touch of a button [18, 38]. Modern technologies have an assertive role in this spread, creating new musical meanings and conditions for ubiquitous music. Ubiquitous technologies in music praxis include, among others, do-it-yourself (DIY) practices, web applications, tactile interfaces, and microcontrollers– based on the social-cultural context [18]. In particular, supporting technology, materials, and resources from everyday life creates an ideal environment for collaborative artistic practices and motivation for experiential and inquiry learning [10].

Tangible interfaces can function as physical objects from everyday life to manage communication between the user and the computer [27]. In this way, they provide expanded ways of interaction compared to the screen's conventional graphical user interface [1]. Especially in the music teaching-learning process, new forms of expression and creativity have emerged [1, 18] through the construction of musical instruments and artifacts [27]. Apart from the kinesthetic experiences provided by manipulating tangible interfaces, pedagogical actions with tactile interfaces form new multimodal experiences, following a STEAM education mindset [32].

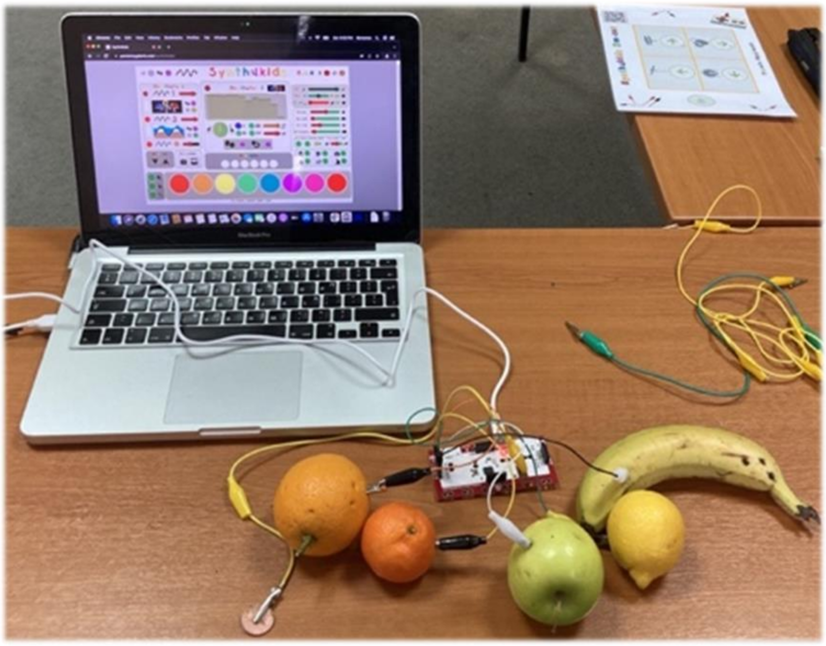

Figure 10. Synth4kids & Makey-Makey™

The use of web applications and interfaces reflects the viewpoints of ubiquitous music. In the case of Synth4kids, the compatibility with the LeapMotion™ device and Makey-Makey™ interface opens new horizons for developing educational activities. More specifically, following a transdisciplinarity perspective, a representative example could be the construction of musical artifacts made of conductive materials, as shown in the following figure.

5.2.2. Augmented Reality (AR)

Augmented Reality (AR) emphasizes the combination of natural and virtual elements in an interactive way that lead to the transcendence of the user's senses to carry out activities that would not be possible without the current technology [2]. Technological equipment –tactile interfaces, sensors, microcontrollers, cameras, and mobile devices– is a prerequisite for an AR tool's smooth operation, usability, and attractiveness [40].

In music, AR can create a more direct interaction between the student and a computer system [12, 15] and is also closely associated with ubiquitous music. Compared to conventional virtual musical instruments that supply limited interaction through the screen, associating visual objects with material things allows kids to interact with music more naturally and intuitively [15]. Synth4kids can provide various AR musical experiences to children. A simple example is the face recognition feature showing a visual presentation on the screen that tracks face movements (see figure 7). Besides, connecting conductive physical objects in the MakeyMakey™ interface and transforming them into music controllers is another characteristic of an augmented interconnection between children’s real and digital worlds.

5.2.3. Internet of musical things (IomusT)

The term Internet of Things (IoT) was developed to describe the vast expansion of the Internet into the real world through everyday physical objects spatially distributed and augmented using information and communication technologies [4]. Internet of Musical Things (IoMusT) refers to real ordinary things related to music processes [38]. Diverse approaches are associated with

IoMusT, from augmented reality musical instruments that use QR Codes [13] to ubiquitous music practices that include the creative use of the Internet, mobile devices, and embedded technologies [18]. Musical "things" –e.g., virtual instruments and interfaces– transform music-making, facilitating music communication, interaction and creativity without necessarily being in the same space [38]. Furthermore, they contribute to music lessons through enhanced and multimodal teaching-learning processes [18, 38].

In the case of Synth4kids, the web-based nature along with the interface communication compatibilities reflect by default the notion of IoMusT. Besides, the compatibility with WebRTC and QR-codes expands the interconnections with devices supporting additional capabilities for authentic music teaching-learning with IoMusT activities inside and outside the classroom.

6. CONCLUSION AND FUTURE PERSPECTIVES

The purpose of the current paper was to present the Synth4kids educational web-audio software. The ultimate aim of the development was to provide new and expanded ways of music interaction, music-making, and learning for the young ages. In that context, the Synth4kids application implements elements from the traditional music-pedagogical methods, combined with cutting-edge technologies in an innovative pedagogical framework for incorporating into music lessons. Furthermore, it gives opportunities for carrying out STEAM activities reflecting project-based and collaborative learning, interdisciplinarity, as well as game-based and authentic problem-solving experiences.

From a technical perspective, the main goal was to create an OS-independent application that could be easily accessible to all students. Synth4kids architecture was based on web-based application development employing state-of-the-art APIs and JavaScript libraries. The tremendous technological evolution in the field of the web during the last years has given the capabilities for fulfilling the ambitious goals of the Synth4kids web application.

Undoubtedly, there is room for many improvements in the Synth4kids features. Numerous updates are in the future plans, based on literature review and users', teachers,' and students' thoughts and opinions during all these years. Referring to elements from traditional music-pedagogical methods, a component that is about to be added is the ability to structure musical scales adapted to user's preferences –not only major and pentatonic scales–, regarding Kodály's perspective that every nation must use their own scales in music education [6]. Considering current trends in music technology in education, blending artificial intelligence elements in music creation could be feasible for allowing the application to form melodies and melodic/rhythmic patterns based on student's performance –call-and-response technique. Furthermore, a simple virtual console consisting of four tracks –bass, drum-machine, arpeggiator, melody– is another future plan, introducing young children to mixing techniques and digital audio workstations (DAWs) handling. A final update to the Synth4kids could be the capability of letting the user handle the sequence of the modules (oscillators, envelopes, effects), giving more freedom to sound experimentation as well as an introduction to modular synthesis.

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REFERENCES

[1] Antle, A., & Wise, A. 2013. Getting down to details: Using theories of cognition and learning to inform tangible user interface design. *Interacting with Computers*, 25, 1, 1-20.

[2] Azuma, R. 1997. A survey of augmented reality. *Presence: teleoperators & virtual environments*, 6, 4, 355-385.

[3] Berman, G. 1999. Synesthesia and the Arts. *Leonardo*, 32, 1, 15-22.

[4] Borgia, E. 2014. The Internet of Things vision: Key features, applications, and open issues. *Computer Communications*, 54, 1-31.

[5] Burks, N., Smith, L., & Saquer, J. 2016. A virtual xylophone for music education. In *IEEE International Symposium on Multimedia*, IEEE, 409-410.

[6] Choksy, L., & Kodály, Z. 1981. *The Kodály context: Creating an environment for musical learning*. Prentice-Hall, Hoboken, NJ.

[7] Cook, P. 2001. Principles for Designing Computer Music Controllers. In *Proceedings of the CHI'01 Workshop on New Interfaces for Musical Expression* (NIME-01), 1-13.

[8] Cytowic, R. E., & Eagleman, D. 2009. *Wednesday is indigo blue: Discovering the brain of synesthesia*. MIT Press, Cambridge, MA.

[9] d'Escriván, J. 2012. *Cambridge introductions to music: Music technology*. Cambridge University Press, New York, NY.

[10] de Lima, M., Flores, L., & de Souza, J. C. 2020. Ubiquitous music research in basic-education contexts. In Lazzarini, V., Keller, D., N. Otero, N. & Turchet, L. Eds. *Ubiquitous Music Ecologies*, Routledge, New York, NY, 109-128.

[11] Dillon, S., & Brown, A. 2010. Access to meaningful relationships through virtual instruments and ensembles. In *International Society for Music Education Proceedings - CMA XII: Harmonizing the Diversity of Community Music Activity*, ISME, 31-34.

[12] Guclu, H., Kocer, S. & Dundar, O. 2021. Application of Augmented Reality in Music Education. *The Eurasia Proceedings of Science Technology Engineering and Mathematics*, 14, 45-56.

[13] Hazzard, A., Benford, S., Chamberlain, A., Greenhalgh, C., & Kwon, H. 2014. Musical intersections across the digital and physical. In *Proceedings of the Digital Music Research Network*, 1-2.

[14] Ho, W. 2007. Students' experiences with and preferences for using information technology in music learning in Shanghai's secondary schools. *British Journal of Educational Technology*, 38, 4, 699-714.

[15] Huang, F., Zhou, Y., Yu, Y., Wang, Z., & Du, S. 2011. Piano AR: A markerless augmented reality-based piano teaching system. *In Third international conference on intelligent human-machine systems and cybernetics*, IEEE, 47-52.

[16] Kokkidou, M. 2015. *The teaching of Music: New Challenges, New Horizons* [in Greek]. Fagotto Publications, Athens, Greece.

[17] Kokkidou, M., & Mygdanis, Y. 2021. Popular music pedagogy in instrumental teaching-learning processes [in Greek]. In Ververis, A. & Litos, I. Eds. *Issues in instrumental teaching-learning: linking theory with practice*, Disigma, Athens, Greece, 110-124.

[18] Lazzarini, V., Keller, D., Otero, N., & Turchet, L. 2020. The ecologies of ubiquitous music. In Lazzarini, V., Keller, D., N. Otero, N. & Turchet, L. Eds. *Ubiquitous Music Ecologies*, Routledge, New York, NY, 1-22.

[19] Lizou, M. 2020. Enhancing creativity in the elementary school music lesson: a pilot study. *Unpublished master's thesis*. University of Ioannina, Department of Kindergarten Teachers, Greece.

[20] Magaliou, M. 2008. The kinetic and virtual representations of music and their role in children's musical and socio-emotional development: experimental research in preschool education [in Greek]. *Mousikopaidagogika*, 6, 66-89.

[21] Mann, Y. 2015. Interactive music with Tone.js. In *Proceedings of the 1st annual Web Audio Conference*. Citeseer.

[22] Mygdanis, Y. & Papazachariou-Christoforou, M. 2021. Transformation of music teachers' perceptions of modern technologies into music lessons through a training intervention in the STEAM model [in Greek]. *International Journal of Educational Innovation*, 3, 3, 66-77.

[23] Mygdanis, Y. & Papazachariou-Christoforou, M. 2022. Maker culture activities in a music theory class at a Greek conservatoire setting: preliminary findings from a practical intervention. In E. Himonides, C. Johnson, B. Merrick, A. King Eds. *Proceedings of the 2022 SEMPRE Music, Education, & Technology conference*, 15-16.

[24] Mygdanis, Y. 2018. Synth4kids: An analog synthesizer web application for music teaching-learning. In T. Shopova, T & G. Apostolova, G. Eds. *Digital Revolution in the cultural and social processes*, South-West University "Neofit Rilski," Blagoevgrad, Bulgaria, 229-240.

[25] Mygdanis, Y. 2021. Virtual instruments in music teaching and learning at kindergarten-age: an educational proposal using Synth4kids web-application. In *Digital Culture & Audiovisual Challenges: Interdisciplinary Creativity in Arts and Technology*, 141-149.

[26] Orff, C., & Keetman, G. 1958. *Music for children*. Schott, London, UK.

[27] Palaigeorgiou, G., & Pouloulis, C. 2018. Orchestrating tangible music interfaces for in-classroom music learning through a fairy tale: The case of ImproviSchool. *Education and Information Technologies*, 23, 1, 373-392.

[28] Papoutsaki, A., Daskalova, N., Sangkloy, P., Huang, J., Laskey, J., & Hays, J. 2016. WebGazer: Scalable Webcam Eye Tracking Using User Interactions. *In Proceedings of the Twenty-Fifth International Joint Conference on Artificial Intelligence*, 3839-3845.

[29] Peacock, K. 1988. Instruments to perform color-music: Two centuries of technological experimentation. Leonardo, 21, 4, 397-406.

[30] Potter, L. E., Araullo, J., & Carter, L. 2013. The leap motion controller: a view on sign language. In *Proceedings of the 25th Australian computer-human interaction conference: augmentation, application, innovation, collaboration*, 175-178.

[31] Ruismäki, H., Juvonen, A., & Lehtonen, K. 2013. The iPad and music in the new learning environment. *The European Journal of Social & Behavioral Sciences*, 6, 3, 1084-1096.

[32] Sentance, S., Waite, J., Yeomans, L., & MacLeod, E. 2017. Teaching with physical computing devices: the BBC micro: bit initiative. In *Proceedings of the 12th Workshop on Primary and Secondary Computing Education*, 87-96.

[33] Serafin, S., Erkut, C., Kojs, J., Nilsson, N., & Nordahl, R. 2016. Virtual reality musical instruments: State of the art, design principles, and future directions. *Computer Music Journal*, 40, 3, 22-40.

[34] Serafin, S., Nilsson, N. C., Erkut, C., & Nordahl, R. 2017. *Virtual Reality and The Senses*. Danish Sound Innovation Network, Denmark.

[35] Stead, A., Blackwell, A., & Aaron, S. 2012. Graphic Score Grammars for End- Users. In *Proceedings of the International Conference on New Interfaces for Musical Expression* (NIME), 176-179.

[36] Taylor, B., Allison, J. T., Conlin, W., Y., & Holmes, D. 2014. Simplified Expressive Mobile Development with NexusUI, NexusUp, and NexusDrop. In *Proceedings of the International Conference on New Interfaces for Musical Expression* (NIME), 257-262.

[37] Tobias, E., VanKlompenberg, A., & Reid, C. 2015. Reflecting on changes in practice through integrating participatory culture in our classrooms. *Mountain Lake Reader: Conversations On the Study and Practice of Music Teaching*, 6, 94-110.

[38] Turchet, L., Fischione, C., Essl, G., Keller, D., & Barthet, M. 2018. Internet of musical things: Vision and challenges. *IEEE Access*, 6, 61994-62017.

[39] van Krevelen, D. W. F., & Poelman, R. 2010. A survey of augmented reality technologies, applications, and limitations. *International journal of virtual reality*, 9, 2, 1-20.

[40] Wang, G. 2014. Principles of Visual Design for Computer Music. In *Proceedings of the Joint International Computer Music Conference and the Sound and Music Computing Conference*, 391–396.

[41] Wigdor, D., & Wixon, D. 2011. Brave NUI World: designing natural user interfaces for touch and gesture. Elsevier, New York, NY.

[42] Williams, D. 2014. Another perspective: The iPad is a REAL musical instrument. *Music Educators Journal*, 101, 1, 93-98.

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