Designing an Accessible Web App to Teach Piano to Students with Autism

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ABSTRACT

Guidelines for teaching music to children with autism mainly focus on the environment and activities, often neglecting how to deliver music instructions in an accessible and effective way. Technology-enhanced intervention offers a structured, repeatable, and coherent training environment, which can be modulated according to the student's needs. The *Suoniamo* app is specifically designed to help students with autism learn to play music in a visually structured way. The app is co-designed with professionals experienced in training people with autism. It provides modules for learning how to read, identify and interpret musical notation (note position and values, pauses, etc.) on a virtual piano keyboard. After this structured training, the child may generalize mastered concepts on a real piano, being able to interpret notes, rhythms, pauses and simple scores in the pentagram.

Preliminary results of a pilot study with three students with autism appear to confirm the validity of the proposed approach.

CCS CONCEPTS

Human-centered computing~Accessibility systems and tools • Social and professional topics~People with disabilities

KEYWORDS

Co-design, Music, Autism, Accessibility, Usability, Web applications.

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1 Introduction

Music is a complex language, and playing an instrument well requires long training involving many skills. Individuals with cognitive disability often have problems paying attention, decoding notes and time, coordinating hands, and so on, thus for them could be difficult to learn how to play music. To empower them, it is necessary to exploit their strengths and mitigate their weaknesses.

Autism, or rather autism spectrum disorder (ASD), is a syndrome that greatly affects an individual's everyday life. The fifth edition of the "Diagnostic and Statistical Manual of Mental Disorders" defines autism as delays or anomalies appearing in children before age 3 years in at least one of three areas: social interaction, communicative and social use of language, and symbolic or imaginative play. ASD compromises a person's ability to interpret the world and what is happening around him/her. People with ASD may have communication deficits, be dependent on routine, be highly sensitive to changes in their environment, or be focused on inappropriate behaviors. The symptoms of people with ASD fall on a continuum, with some individuals showing mild symptoms and others whose symptoms are much more severe. As symptoms vary significantly from individual to individual, a personalized educational intervention can offer better results, exploiting personal abilities and matching an individual's needs while adapting to his/her learning pace.

The CDC's Autism and Developmental Disabilities Monitoring (ADDM) Network estimated that "about 1.7%, or 1 in 59, of 8-year-old children were identified with ASD, based on tracking within 11 communities in the United States" [9]. Considering the high incidence of autism, it is very important to start educational and behavioral interventions in the early years of life, in order to exploit the great plasticity of the child's brain [31, 34].

According to the empathizing-systemizing theory discussed in [29], a highly structured intervention can lead to positive learning outcomes in children with ASD. In fact, in a clear and simple interaction environment, children with ASD can effectively access learning, benefiting from repetition and progressive difficulty levels. A highly structured learning environment means that the exercises and trials are offered in a systematic and predictable way (e.g., increasing difficulty, repeating the same trial several times, keeping learning activities consistent across lessons). This makes objectives clear and predictable, preventing frustration or anxiety while generally increasing attention and reducing self-stimulation. This evidence suggests that it would be easier and more accurate to exploit technology in the intervention. Technology can offer repetitive and predictable sequences of trials, avoiding human error and eclectic interventions that could confuse people with ASD and possibly hinder the learning process [20, 24].

The *Suoniamo* project aims to create an application for teaching music to children and adolescents with autism. The application provides a structured learning environment including:

- User interfaces that are simple, clear and responsive
- Errorless environment: the software prevents the user from making an error in the first phase of the learning process in order to prevent memorizing erroneous information.
- Reinforcement (e.g., animated gif), to encourage the user to increase positive behaviors
- Visual prompts (i.e., color on the virtual keyboard notes, the time progress bar), which gradually disappear, depending on the student's progress.

The paper is organized in five sections. Section 2 introduces the background of this study: related work and two popular apps for teaching music. Section 3 describes the *Suoniamo* app including the participative design and functional requirements as well as the architecture and interfaces. Section 4 introduces the pilot study with three adolescents with autism and discusses preliminary results. Last, discussion and future work end the paper.

2 Background

In the last 20 years the Internet has revolutionized our life, simplifying a vast amount of services and tasks, including learning. Digital learning resources are available 24 h/day, for as many times as required, and are customizable according to a user's needs. The *Suoniamo* application provides a tool to help students progressively learn music in a structured way, so in this section we will focus on research, and methodologies for teaching piano, especially for people with autism. Analyzing apps to teach music, we observed that none are specifically designed for users with autism. We then have analyzed most frequently used apps looking for any interesting features to be translated to our domain.

2.1 Commercial Apps

Mobile devices are usually preferred by children and adolescents since they can easily manage their small size and interact via natural gestures (touch, drag, tap). Several apps are available in online stores (Google play, Apple store) to teach music to children or novice learners who want to understand music principles or play an instrument. Most apps for delivering basic music concepts rely on color, used to highlight the correct items to play.

We analyzed numerous apps (Musicope, Android Piano Master, Virtual Piano, Chrome Music Lab Suite, etc.), but we will describe only the two that are most frequently used and more complete in terms of delivered functions and visual training programs: Synthesia[1] and Simply piano[2]. These two very popular apps, for music training, exploit features suitable for teaching individuals with autism to play music, by providing visual cues to drive playing the music. Synthesia uses small bars that fall down on the piano keyboard to indicate the notes to play and disappear when the finger is lifted. Actually, Synthesia is a game for training the student to play the piece of music. However, videos reproducing the vertical pentagram of Synthesia music sheets are very common and are used by piano students. As we observe in Figure 1, different colors are used to indicate which hand to use (blue for the left and green for the right), a different width of the bar distinguishes the notes vs the semitone (narrow rectangle equal to the size of the key on the keyboard), and the length of the bar indicates the duration of the note. The time notion is strengthened by the disappearance of the falling bars as time goes on. No information is provided to suggest which finger to use to press the key (fingering technique). The vertical pentagram simplifies playing the music in a non-traditional way, different from the standard pentagram.

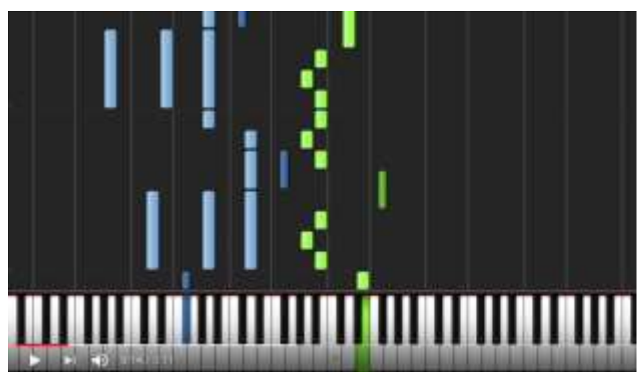

Figure 1: Synthesia App

Simply Piano (Figure 2) helps familiarize the student with the notation used in the standard pentagram, highlighting the note to play as the execution progresses over time. In this way, reading notes is facilitated because the student performs the training directly on the piano keyboard, and the use of the standard

[1] https://www.synthesiagame.com/
[2] https://www.joytunes.com/simply-piano

pentagram can foster knowledge by use. A microphone records the student's execution, allowing real-time feedback, both visual and auditory, and supporting understanding.

Synthesia is also easy to use for people who do not know classic music notation, as it does not require knowing how to interpret the pentagram (offering a visual vertical pentagram to favor the execution, showing note positioning on the piano and its value progressing over time). However, since Synthesia is very rich in stimuli, it may not be suitable for people with low-functioning autism. Moreover, in pursuing an educational project, we also wish to teach individuals with autism how to interpret classic music language notation, as Simply Piano does, for people wishing to learn the piano.

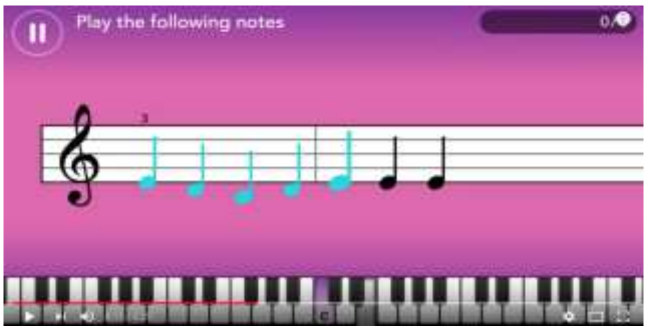

Figure 2: Simply Piano App

The *Suoniamo* app attempts to integrate both concepts: it exploits the visual channel, using visual cues to interpret the standard pentagram and offer help to the children, e.g., using a progressing bar to convey the concept of note duration. Furthermore, it delivers structured teaching in small elementary units, avoiding errors and modulating the stimuli. Personalization features enable better matching of the student's personal learning rhythm and preferences. The main difference between *Suoniamo* and the analyzed apps is the possibility of further simplifying and personalizing the experience according to the student's abilities, i.e., the opportunity to retain more control over the app's functionalities. Moreover, the software is free, shared under the CC license in hopes of encouraging its adoption by music teachers, parents, and therapists who want to use music training programs for people with autism.

2.2 Related Work

Literature reports the positive effects of music in treating specific symptoms in autism spectrum disorder. Summarizing a recent review concerning music interventions for children with autism [14], twenty studies focused their attention on music's influence on *communication*, *socialization* and *behavior*.

Concerning communication, music has been used to improve expressive and receptive skills in different ways, such as using text sung or spoken to music or a rhythm [5], or using improvisational music [5, 15]. The use of music for socialization mainly used engagement as a focus of the research, one study using music to decode emotions [11]. All studies showed improvement in peer-initiated interaction, but generalization and lasting effects were not shown [8, 28]. Finally, most studies cited in this review focused on using music to increase appropriate behavior and reduce vocal stereotypy. Approaches adopted included music listening and music combined with social stories [21]. General results reported in the studies examined were positive, but not all individuals with autism find listening to music a positive experience [32].

Other literature attempts to verify the expression of particular abilities in music perception, and sometimes the presence of higher than average skills, in people with autism [27].

Unfortunately, very few studies provided opportunities for individuals with autism to learn music, or to be included in music classes. There is a gap in the area of effective music teaching, and our contribution, described herein, attempts to fill this gap by exploiting a multidisciplinary study of effective strategies to teach music to people with autism using a software tool. Apart from the benefits of music therapy, there is some evidence in literature on the benefits of music for people with social and communication difficulties, especially regarding visuo-spatial, logical-mathematical and intrapersonal skills [3, 4, 18].

A doctoral thesis [33] investigated how individuals with ASD can have optimal learning experiences with music, using a qualitative approach [6] based on interviews with four music teachers working with individuals with ASD (one drum and three piano teachers). The teachers detected three elements for successful teaching: 1) Music as the goal (fostering music enjoyment and experience), 2) Different levels of success (adjusting expectations for each individual) and 3) Positivity (creating opportunities for empowerment and confidence). Moreover, the valuable contribution of the thesis is identifying strategies that can serve as guidelines for music teachers to implement the previously described elements:

- Concrete strategies (tools used to accommodate needs)
- Stylistic strategies (non-traditional and flexible teaching approaches)
- Attitudinal strategies (greater understanding of students).

These strategies need to be adapted to a specific context; it is impossible to provide a manual on how to teach music to all people with autism because to be effective it should depend on the user's skills and needs, thus becoming strictly personal. We used several strategies in our work, choosing those suitable for implementation in a software tool, as described in Section 3.

In a recent study, Elahi et al. [23] created the Xylotism, an interactive tablet game app to improve learning and teach music to children with ASD. The application represented a virtual environment combining two software tools, a Nima Robot [3] (frequently used in other research studies involving individuals with autism) and a Xylophone (software version) proposing two

[3] https://www.softbankrobotics.com/emea/en/index

training modalities. One invites the child to play notes through a 1/8 keyboard that simulates a xylophone; the other offers interactive exercises with the Nima Robot that asks the child verbally to perform some tasks of differing complexity, such as touching a certain note (simpler case), or reproducing a certain rhythm (more complex). Every action of the child's triggers a software feedback -- a reward (correct action) or an encouragement to try again (wrong action).

However, the training path does not offer a modular framework for learning different musical concepts, exercises are basic and mainly rely on eliciting task imitation guided by the robot, which usually motivates children with autism. Moreover, the study does not offer information regarding the app's user interface design, specifically addressing users with special needs, nor the interaction mechanisms and workflow.

The same robot was used in another study by Taheri et al. [2] as a way to teach the fundamentals of music to children with autism (read/play the notes and simple musical sentences). For all of the participants (three children with high-functioning and one child with low-functioning autism), the authors reported improvement in fine hand imitation, using both hands in the right order, and in rhythm identification.

3 Designing the Suoniamo App

The target users of our research work are adolescents with autism (age 11-14 years). Two recent studies explore the requirements for building user interface for users with autism spectrum disorders in specific cases, such as the creation of an open book [25] or the realization of touchscreen-assistive learning numeracy app (TaLNA) [22]. Pavlov's work [25] indicates several UI design recommendations covering all aspects such as presentation, navigation and page loading, interaction, multimedia usage and personalization. Kamaruzaman's work [22] shows in the graphic design of the numeracy app for children with autism how to apply the five principles of Lewis [7] in designing a user interface. Both contributions offer valid guidelines for a general and specific design that have to be further specialized in the current domain, requiring the guarantee of high interactivity and User Experience preserving the positive role of music as a learning topic.

All the UI components, basics or augmentatives (as described in the paper), were the result of literature analysis together with iterative evaluation of mid-term prototypes conducted during co-design sessions involving professionals having different learning experiences with people with autism.

We focused on participative design in order to satisfy accessibility/usability aspects that are relevant when designing for special needs people, also taking into account individual needs, as described in the following.

3.1 Co-design and Functional Requirements

Co-design sessions involved a psychologist, a music teacher specialized in supporting children with disability, a biomedical engineer, a telecommunications engineer and two computer scientists. They were scheduled from April 2018 until the present every two weeks through Skype sessions, also sharing screens when useful with a psychologist and a music teacher, both experienced in teaching music to children and adolescents with autism. We used a collaborative platform to share materials, realized mockups to better illustrate the user interface proposals of the intermediate design steps, and developed several prototypes to allow the experts to better evaluate the learning module. A preliminary phase involved the analysis of popular apps for teaching music (Synthesia, Simply Piano, etc.) and the related literature. The objective was to be acquainted with current strategies adopted by the music teachers working with students with autism, and to evaluate music learning strategies embedded in digital tools, in terms of effectiveness and adaptability to this particular domain.

Initial results highlighted two aspects related to the definition of a music learning path for people with autism:

- The need for a structured environment with scheduled times, activities and procedures adapted to the needs of the individual;
- The lack of a standard methodology, since each teacher uses creative and personal didactic approaches.

In addition, comparing the features offered by the most popular software tools for learning music, we realized the shortage of tools supporting both the learning of the most relevant concepts in the music field and the execution of songs. Completeness could offer long-lasting concepts learned and improve generalization skills since it is not based exclusively on a stimulus-response dynamic (learning through imitation).

As previously mentioned, reducing environmental stimuli helps children concentrate, avoiding non-useful input that might provoke anxiety and hinder learning. Functional and non-functional requirements have emerged during this phase and their definition has been improved time after time by testing different implementation solutions with particular attention to the user experience. Among functional requirements, those strictly related to the learning environment include:

1. adopting alternative augmentative communication to deliver training
2. offering an errorless environment
3. delivering structured and facilitated teaching
4. prompting the user when difficulty arises
5. using reinforcement in the case of positive behavior, thus increasing the probability of positive behavior in the future, and encouraging children to increase their confidence in solving tasks as well as their self-esteem.

Each one of these functional requirements is associated with a set of non-functional criteria that define how the app performs a specific function, for instance how it applies errorless principles or provides a reward (in the case of successful tasks) to model the user's behavior, etc. These criteria determine specific design patterns for the graphical user interface and the user interaction mechanisms, as described in paragraph 3.4.

3.2 Architecture

Suoniamo was originally conceived as a native mobile application for Android devices, since it was meant to be used as a training platform to be run on the pupils' tablets during music classes. While investigating the state-of-the-art of Android musical applications, we noticed that Android natively provides poor or no support for producing music programmatically. Furthermore, working with the audio Musical Instrument Digital Interface (MIDI) protocol is a key requirement for our application that should provide highly interactive, captivating user interfaces to simulate a piano keyboard, possibly using animations, but this is a difficult task to accomplish using Android's native Java and XML formalisms.

To overcome the limitations of the Android environment, we decided to rethink our application as a web app. A wide range of new APIs exist that are built on top of JavaScript and exploit the capabilities of the latest web browsers' engines. By using them, it is possible to develop desktop-like applications that can be run on different mobile devices, provided that these support the same browser engine and that the app's graphical user interfaces (GUIs) are responsive. As far as music programming is concerned, some APIs leverage the latest browser technologies, making it possible to create web pages that produce and respond to musical input or render musical scores dynamically. Furthermore, creating complex graphical user interfaces and animations is almost straightforward when using web technologies such as HTML5, JavaScript and CSS. After thorough investigation, the following web APIs were individuated for the development of our application:

- **Web Audio API**[4]: as stated in the W3C specification, it is "a high-level Web API for processing and synthesizing audio in web applications […] designed to be used in conjunction with other APIs and elements on the web platform". It enables applications based on HTML5 to produce and manage sounds, providing them with the capabilities usually found in game audio engines and desktop audio production applications.
- **Tone.js**[5]: a powerful library that is built on top of the Web Audio API and provides web developers with capabilities such as advanced scheduling of sounds, synthesizers, sound effects and a series of methods that simplify coping with music creation.
- **Nesus UI**[6]: a widely used JavaScript toolkit for creating user interfaces for musical applications on web browsers that support HTML5 (in fact, it uses HTML5 canvas to render the graphic elements). Since its interfaces are responsive, it is the ideal choice for a web app to run on a mobile device. **VexFlow**[7]**:** a music notation rendering API based on JavaScript. It leverages HTML5 canvas and SVG to render musical scores on web pages. Some visual effects such as styles and animations are also supported.

3.3 Defining Learning Programs

An interesting challenge concerns the definition of the teaching **methodology** applied when teaching music to children with low-functioning autism. Most interventions originate from eclectic and creative teacher approaches, while clear guidelines have not been shared up to now. In order to outline this methodology, it was crucial to define the key concepts that allow the subject to learn music and to define priorities, i.e., what should be generally taught before and what after, and the modalities, i.e., how these concepts should be taught.

Obviously, it is necessary to specify this definition within the autism domain. The latter aspect raises further questions; among these is the need to know and take into account elements such as music perception and cognition typical in most children with autism who do not possess 'savant talent' as defined by Treffert [10], as well as the need to know individual specificities in learning preferences; for example, the subject could be more 'auditory' or more 'visual'. For this reason, the *Suoniamo* application exploits both the visual and auditory channels, and is customizable in a number of parameters as detailed in the following. The app is intended to be used under the music teacher's supervision, who can select which educational modules to assign to each student and set customized parameters.

The goal of the system is on one hand to support learning musical theory concepts, and on the other to offer a structured environment for playing simple music pieces in which to practice the concepts learned.

We started designing a set of basic programs and learning units that the teacher selects for each student according to his/her competence and progress over time.

1. *Note discrimination*. Playing a single note (C, D, E… or DO, RE, MI,..) regardless of duration, in order to learn the position of notes on the keyboard. In the beginning, notes are proposed in sequence to help memorize the scale. Once this skill is learned the student can move to program generalization (i.e., play random notes) and once mastered, (s)he can progress to the next learning unit.
2. *Note duration discrimination*: play a note for the duration indicated (4/4, 2/4, 1/4). This program also includes training in the pause concept. The training includes three units: starts from whole note (4/4) proposing trials on notes in sequence also introducing the pause (4/4). Once this concept is mastered, the training moves on to half notes (2/4) and next (having mastered the previous one) to quarter notes (1/4).
3. *Scale*. Playing a C scale, to learn the central, left and right scale on the keyboard. This training shows in the pentagram the entire scale to be playedd starting from whole notes at the beginning, and once mastered, moving on to half notes and next on to quarter notes.
4. *Assonant Chords* (C chord, D chord, etc.), to learn the notes composing the chord (notes pressed together). The training starts with two notes to be played at the same time and next moves to three notes played together. Single voice score, training to play a simple music sheet to perform with one hand.

[4] https://webaudio.github.io/web-audio-api/
[5] https://tonejs.github.io/
[6] http://nexusosc.com/api/#nexusui-api
[7] http://www.vexflow.com/

The training starts from one bar or measure and once mastered adds the next one. The melody is usually played with the right hand and the accompaniment with the left hand.

The choice of assonant chords and a single voice score was suggested by the music and special education teacher, experienced in training children with low-functioning autism, in order to limit the difficulty for the student. As previously mentioned, the role of the teacher is valuable and the digital tool has to support (and not interfere with) his/her work, guaranteeing consistency and homogeneity of instruction.

3.4 Graphical User Interfaces and User Interaction

Considering the learning units described above, the student's work environment should guarantee:

a) A logical workflow of tasks
b) Fluid design of the graphic components of the user interfaces (UIs)
c) Appropriate design of the student/system interaction component.

Point a) highlights the importance of clear task requests from the system; the student needs to know exactly what to do (avoiding disorientation), having to perform highly predictable actions. In people with autism, difficulty interpreting reality creates confusion and anxiety, which can inhibit the individual's action, leading to problem behaviors. Often, especially in unfamiliar contexts (real or virtual, such as those coming from a software application), it is sufficient to order and schedule the requests to avoid a halt and enable the individual to respond positively to the request. In our case, it means proposing one task at a time, avoiding the possibility of error and maintaining consistency between instructions and visual stimuli.
Point b) emphasizes the role of the graphic components of the UIs that come into direct contact with the student. They must comply with a set of intrinsic requirements and appropriately enhance the workflow design (point a). In fact, even well-structured tasks can be invalidated by inappropriate graphic components.
We designed each UI as a dynamic entity that exploits the user's visual channel to convey information (people with autism are often visual learners [13, 35]). Each UI includes basic elements of the specific domain (piano-keyboard, music notation, etc.) and elements defined as 'augmentative' that implement accessible learning strategies. Augmentative elements adapt forms and content of the learning program to the individual's characteristics and to the requirements of the music program. Of these elements, the most important is note-color mapping to simplify note identification and positioning on the keyboard. The note-color combination has different origins ranging from philosophy and history of vision to optical physics, and is frequently used with neuro-typical children. Moreover, some subjects with autism have "synesthesia," an ability to associate musical notes with colors, shapes, etc. [30]. For these reasons, we implemented the association note-color proposing as default combination the rainbow spectrum, customizable by the teacher in the case of different needs (Figure 3).

Figure 3: Note-color map

Another augmentative element has been introduced to help the student learn the concept of time duration; time duration and progression are conveyed through a progress bar calibrated on the time signature (the default is 4/4). As the student presses the key on the virtual keyboard, each quarter progressively fills in. Moreover, the correct answer is suggested by a light color, becoming stronger as the time progresses (brightening).
The user interface adds these augmentative elements (acting as visual prompt) as default at the beginning but they can be progressively faded (by the music teacher) when the student's learning progress reaches a high percentage of success.
Other general requirements for the GUIs are minimalist design, avoiding background and distractors, appropriate use of colors (soft or mild colors, not very bright colors) appropriate fonts (clear, sans-serif fonts with contrast between font and background, and without transparent images and text overlap), structure and order of components (few elements on screen, each one with a clear function), and consistency between instructions and visual stimuli.
Regarding point c), user interaction needs to be evaluated attentively since the student interacts with a simulated piano keyboard that, in order to be effective, must release immediate feedback through sounds. Instant feedback has great importance especially in time-based tasks (such as note-duration, pause training). Thus, a visual prompt (a smile icon) is provided after a correct trial in order to favor comprehension of the required task. Furthermore, since piano simulation is better conveyed by touchscreen devices, fluid layout guarantees smooth adaptation for different screen dimensions, which can simplify the interaction [1, 26]. Other characteristics applying users' interaction requirements coming from the co-design sessions:

- The errorless environment, which provides no sound if the student presses the wrong key on the virtual piano keyboard
- Appropriate system behavior in case of error; in the case of student error in a trial, the same trial should be proposed again.

The visual and auditory reinforcement (animated smile icon) that provides a neutral or positive reward (not negative ones, to avoid frustration). The smile icon appears neutral at the beginning (no interaction) and becomes positive emotion or stays neutral, depending on the task completion, if successful or failed.

3.5 Learning Units

Co-design sessions were performed every 2 weeks. In the beginning, the different languages (psychology, computer science, music, pedagogy) and skills of participants made it difficult to begin the design process. However, after 2 months the language and skills were shared among all participants and ideas started to take shape, creating the first learning module prototypes.

The design and implementation of technology-enhanced programs progress from basic to more complex ones. The prototype of the first module (Note Discrimination) was created and then tested by design participants refining the visual appearance of the interface. The generalization after mastering the skill on the tablet is to reproduce it on the piano keyboard, under the music teacher's supervision and prompting (if needed). Figure 4 shows the Note Discrimination User Interface (regardless of note value) to learn the position of the note on the keyboard and its notation on the pentagram.

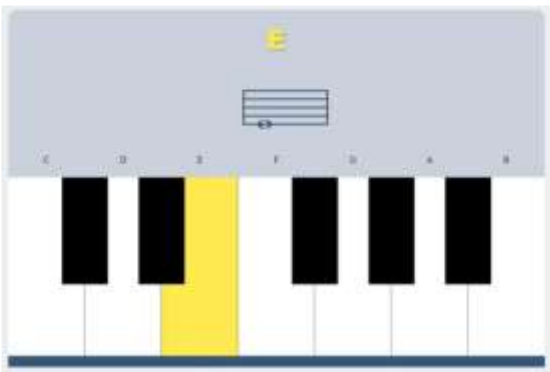

Figure 4: The Note Discrimination UI

Next, the second module was created for teaching note duration, as shown in Figure 5, and the prototype was implemented and tested in the co-design sessions.

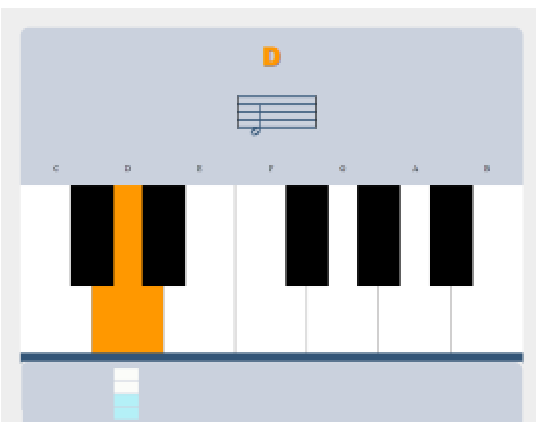

Figure 5: The Note Duration Module UI (first prototype)

Each learning unit proposes random trials (e.g., play E, play A) twice in order to reinforce the concept. However, the number of iterations of each trial is a customizable parameter; teachers may modify the default setting according to the student's needs.

Results of co-design sessions suggested several interface improvements:

1) Optimizing the web interface by moving the visual time cue up in the interface on the right side of the pentagram fragment, increasing its visibility, which might be obscured by the child's finger during touch interaction with the screen
2) Adding feedback to immediately deliver to the user the information of a successful trial. For this, a neutral smile has been added on the left side of the upper part of the user interface.
3) Introduce a discriminative stimulus for the required action (PLAY label on top of the interface)

Figure 6 illustrates the user interfaces of the learning unit Note Duration.

The program on note duration discrimination proposes as default, trials of notes in sequence (C, D, E… , B). Anyway, if the child makes an error, for instance playing F for 2/4, (i.e., releases the pressed key early or late) a vocal alert is played, and the same trial is proposed once again (i.e., same note and duration). The teacher can modify this default configuration to favor the subject's learning process.

4 Pilot Test

As previously mentioned, the Suoniamo app gradually introduces technology-enhanced programs from basic to more complex ones. In order to quickly improve the prototype's usability, we decided to perform an intermediate pilot test with students and teachers after the development of the first two learning units, to collect impressions and feedback. Indeed, implementing the Web interface brings some challenges -- first of all, synchronization when teaching note duration and rhythm. Delay in fact would hinder learning.

Since co-design with a student with low-functioning autism is challenging, we aimed to observe them early in the interaction. The aim was to collect feedback about the UIs and the usability of the application at the first phase of implementation in order to accelerate development of the new learning units with better understanding of user needs and preferences.

4.1 Method

The first pilot test was performed with three adolescents with diagnosed autism (age 15-17 years); two of them are low-functioning (no verbal), one is medium-functioning, able to speak roughly. None of them had any previous musical knowledge but all were sufficiently familiar with the use of mobile touch screen devices. The test was carried out in a natural setting at school, where these students are in care of a special education teacher in a one-to-one interaction. The students' teacher was present during the test, only as an observer, to make students more comfortable during the session. However, the teacher was asked to reinforce the student in the case of success. Besides, introducing the special needs teachers enables feedback collection and makes them familiar with the app, which could be exploited during curricular lessons.

Parents of participants signed agreements on data privacy (according to EU and Italian law). Data have been anonymized and we received written consent to process, analyze and publish any data collected during the user test.

The room where the test was performed is an open space with two sofas, two tables and many pillows, a common space shared with students with disabilities.

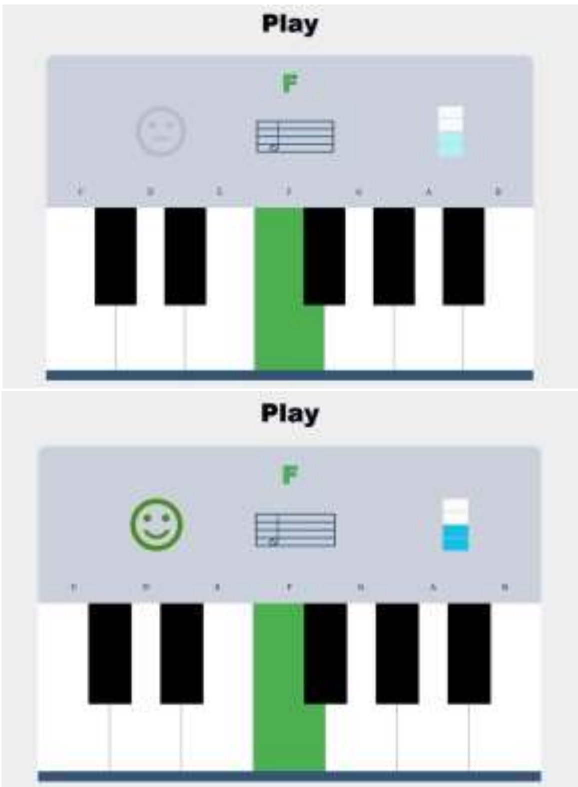

Figure 6: The Note Duration Module UI (new interface): before and after correct successful trial completion

All participants interacted with two learning modules: Note Discrimination and Note Duration. Specifically, two tasks were proposed:

- T1: discriminate all notes in the C scale. The app proposes the note in the ascending order in the learning phase.
- T2: play, pressing the correct note for the requested value. The app proposes the note value in 4/4, 2/4 and ¼ time configurations.

Each of the two learning modules (Note discrimination and Note duration) has a basic exercise, with the sequence of the proposed trial according with the notes scale (C, D, E, etc.) and an advanced exercise that proposes the trials randomly. In this preliminary test, we do not assess the advanced exercises, but we were interested to obtain early feedback from users on the user interface accessibility and pleasantness.

The special education and ABA supervisors of the users act as mediators. One researcher explains the app functionalities verbally and shows, visually, how the app runs, to facilitate imitation. All participants were attracted by the app, as usually happens with electronic devices.

During the test, if a participant makes an error the mediator provides a physical prompt with the hand. To avoid frustration, if the participant performed three errors, the test moves to the next trial.

For evaluating the degree of acceptation of the app, Likert visual scales were used. To also enable the low-functioning students to answer the questions, an icon scale was printed on paper, asking the user to indicate their preferred answer. Specifically, as suggested in literature to collect opinions from children and young users [12, 17], the pleasantness of the user interfaces was evaluated by participants through a Smiley-meter Likert scale (awful, not very good, neutral, good, very good). Literature reports the feasibility of this rating scale also for subjects with autism [16, 19]. The mediator was fundamental in this phase since low-functioning students use the PECS (picture exchange communication system) to communicate.

The effectiveness of music training was evaluated by observing and annotating any student's errors.

4.2 Results

Preliminary results were encouraging: we observed that all participants liked the user interfaces and were engaged by the app use. Two participants found the interaction easy and performed both tasks correctly; they were the medium-functioning user and one of the low-functioning students, who is used to technology-enhanced training programs and has performed ABA from age 5. The other low-functioning participant had difficulty with the Note Duration task, in all the different time configurations.

Considering, for both tasks, T1 and T2, the following error types:

- Touching a target different from the required note (E1)
- Touching a non-interactive UI element (E2)
- Pressing the target note for a duration different from the one requested (E3)

Results of the test are shown in Table 2.

Thanks to the visual color-based relation between notes and piano keys, the first module was simple for all participants, who were able to press the correct key on the virtual piano keyboard. Concerning the Note Duration module, we observed some difficulties in the low-functioning participant who was not used to structured teaching. He was unable to keep the note clicked as long as required, and was helped to correctly execute the trials with physical prompts. However, he was very excited to be able to solve the trial and receive positive visual feedback. He expressed his excitement clapping his hands. The mechanism of filling squares was easy for the medium-functioning participant and the ABA-trained participant, while this low-functioning student would probably have needed preliminary training to become familiar with the structured teaching environment.

Table 1. Results on success (completion without errors, S) and errors (E1, E2, E3)

Subject / Task	**T1**	**T2**
U1	S	S
U2	S	E2, E3
U3	S	S

Considering user's preferences, evaluated through a Smiley-meter rating scale of 5 items (awful (1), not very good (2), neutral (3), good (4), very good (5)), results are shown in Table 3.

Table 2. Users' preferences

Subject/Task	**T1**	**T2**
U1	4	4
U2	5	4
U3	5	4

5 Discussion

Literature suggests the positive effects of music in the treatment of specific symptoms in ASD, helping improve communication, socialization and behavior. To enhance the learning of music and piano for subjects with autism, we designed and developed a web application. The design was participative in order to satisfy accessibility/usability aspects relevant for these target users. Children and adolescents with autism, especially low- and medium-functioning individuals, can benefit from an accessible and highly structured learning environment, so the application was designed to support music programs ranging from basic concepts to more complex ones in a structured way. Each learning unit proposes exercises in a default setting, but the trial choice and the number of repetitions of each of them are customizable parameters; teachers can modify the default setting with a personalized one for students with specific needs and preferences.

Design and implementation proceeded gradually, with preliminary user tests. Results of the pilot test on two learning units of the web application *Suoniamo* appear to confirm the feasibility of the proposed approach, i.e., using technology to foster and support music learning for children with autism.

This early step was intended to rapidly catch flaws regarding interaction in the prototype. A more accurate evaluation of all the *Suoniamo* learning units with a greater number of students with ASD is scheduled for the beginning of the next school year (October 2019–March 2020).

At present, the development is progressing to the learning units regarding assonant chords and one voice score, which are directly derived from previous modules; by increasing the complexity of the execution, they are more challenging for students with autism and intellectual disability.

We also are setting up agreements with a local Autism Association and four schools geographically distributed around the country in order to enroll 16 adolescents with autism for a 6-month test; eight users will carry out the technology-enhanced programs and eight will be a control group that will perform the regular curricular lessons. We also plan to extend the test to other special needs users, expanding the sample to also include other children and adolescents with intellectual disabilities.

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