A Web Platform to Foster and Assess Tonal Harmony Awareness

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Abstract. This paper investigates the use of computer-based technologies applied to early learning of tonal music harmony, a topic often considered too abstract and difficult for young students or amateurs. A web-based platform is described, aimed at fostering and assessing harmonic awareness in children by leveraging on chord perception, gestural interaction and gamification techniques. The application guides young learners through 3 experiences towards the discovery of important features of tonal harmony, where they can listen to melodies or chunks of well-known music pieces and associate chords to them. Users' actions during the experiences are recorded and analyzed. An early experimentation with 45 school teachers was conducted with the goal of assessing the usability of the application, the level of acceptance by teachers, and prototypical behaviors during the experiences. The results provide guidelines on how to evaluate user performances, as well as useful indications for further development of the platform.

Keywords: Music learning · Computer-supported education · Tonal harmony · Web · Automatic assessment

1 Introduction

Music technology is playing an increasingly important role in educational activities as well as in the dissemination of culture and musical practices. This is due not only to the impact of both national [27,48] and European [15] government policies aimed at supporting innovation in schools, but also to the growing availability of electronic devices (electronic keyboards, computers, digital audio workstations, etc.) both in school laboratories and at home. Moreover, portable devices such as tablets and smart phones are endowed with a great number

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of applications for creating (e.g., GarageBand[1], Songify[2], Animoog[3]), listening (e.g., Spotify[4], Pandora[5], iHeartRadio[6]) and learning music (e.g., Simply Piano[7], Yousician[8], and Uberchord[9]), thus allowing educational training also outside a traditional school environment.

This outstanding development implies not only an increase of technical knowledge for the management of electronic devices, but also a shift in the conception of musical teaching and, ultimately, of music itself. The problem of integrating technology effectively in the classroom has been addressed by Mishra & Koehler by introducing the "Technological Pedagogical Content Knowledge" framework (TPACK) [26]. According to TPACK, teaching with technology does not mean simply to embed new devices in classroom practices, but rather to take into account the complex interrelationships that connect at least three knowledge domains: content, pedagogy and technology. Thus, the teacher must be able to mediate between her domain expertise and the technological representation of the concepts; she must employ pedagogical techniques to derive all the advantages offered by the new educational means and to provide adequate monitoring of students advances.

The introduction of technologies in the instructional design implies also the involvement of new learning styles and situations. Formal learning – where the activity is sequenced beforehand and has a predefined aim – and informal learning – where the activity is not sequenced beforehand and is steered by the development of the work – are the two cornerstones of a continuum along which various mix ups of both teaching approaches can be placed [16]. In this extremely varied context, *constructivism*, i.e. the theory of learning–by–doing, finds its full realization. Originating from the thought of Piaget [31] first and then of Papert [29], constructivism underlies many music education experiences which draw greatly from advances in music technology [47]. Consequently, other important aspects of teaching are affected by these changes such as didactic planning and management of the class group. In this regard, the blended learning approach that sees the coexistence of classroom and online activities offers some interesting outcomes, because it allows the possibility of designing student-tailored learning approaches, flexibility and the freedom to learn anytime and anywhere, social engagement and experience sharing with teachers, class mates and internet communities [11].

Digital technology not only allows to reach new musical domains but also changes the way knowledge is communicated [46]. According to Brown [5, pp. 6–12], computers in music education can be profitably used to amplify musicality,

1 https://apps.apple.com/us/app/garageband/id408709785.
2 https://songify.en.uptodown.com.
3 https://www.moogmusic.com/products/animoog.
4 https://www.spotify.com.
5 https://www.pandora.com.
6 http://www.iheartradio.ca.
7 https://www.joytunes.com.
8 https://yousician.com.
9 https://www.uberchord.com.

by acting as a simple tool, as a medium, and as a musical instrument. In the first case, traditional tasks such as writing and playing music back can be performed more accurately and in a shorter time, but they remain essentially the same as with paper, pencil and piano. In the second case, the transformative power of computers produces a significant shift in the very nature of the matter treated [3]. For example, the editing tools of a digital engraving software may be used to copy, paste and transpose sections of the musical work. Finally, computers can be profitably used as musical instruments, too. For instance, tunes can be programmed in terms of MIDI messages, musical textures can be altered through timbral changes and DSP effects, and a number of devices (e.g., mouse, touchscreen, webcam, tangibles, attached sensors) can further enrich the expressive possibilities. Such dramatic changes envision contexts where musicality is not only expanded thanks to technology but begins to be inextricably connected with it. Creative activities and artistic practices such as designing performance environments or synthesizing new sounds depend strictly on computers, technological devices and musicians' programming skills.

But amplifying musicality means not only providing new fields for music creation but also expanding music curricula [41] and experimenting how to extend the limits of knowledge of musical structure and theory in a new and unprecedented way. This is the aim of *Harmonic Touch*, a web platform for the study and practice of tonal harmony which leverages on harmonic perception, embodied cognition and gamification in order to introduce primary and middle school students to a set of experiences focused on harmonic skills and awareness.

Finally, a key problem connected to the use of technology in music education is assessment. In general, technology-based assessment is considered more reliable and efficient in collecting and recording data. It allows analysis and provides rapid feedback for participants and stakeholders [13]. In the musical domain, automatic quantitative assessment of music performance can provide a sound and objective feedback to students, particularly when the supervision of a teacher is not available [44]. For teachers, automated performance assessment is useful to collect large amount of quantitative data, also providing metrics to assign student grades [38]. Automatic assessment of users performance is also a necessary element in games for music education where scoring systems may track their progress and provide feedback for self-assessment and engagement [40].

Focusing on the specific goal of fostering tonal harmony awareness in young students, the remainder of this work is structured so as to reflect this multifaceted vision: Sect. 2 will introduce the musical background which can serve as a reference point for the following discussion; Sect. 3 will provide details about *Harmonic Touch*, a web platform that proposes three exercise models to gain tonal harmony awareness; Sect. 4 will analyze experimental results; finally, Sect. 5 will draw conclusions.

This paper is an extension of the work presented at the 11$^{\text{th}}$ International Conference on Computer Supported Education (CSEDU 2019) [25].

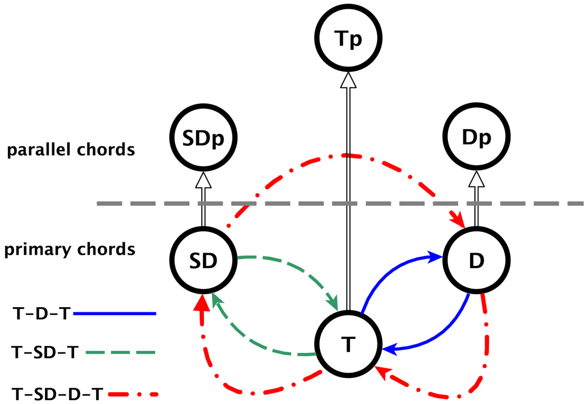


Fig. 1. The spatial arrangement of primary and parallel chords and three common chord progressions [25].

2 Fundamentals of Tonal Harmony

Tonal harmony has been systematically defined by Rameau in 1722 [32] and, since then, it has been adopted in many musical styles, from Baroque to contemporary popular music [6,21]. As we live in a world where tonal music is pervasive, we have been subjected since our childhood to music stimuli which solicit the brain to build an internal understanding of musical structures according to their tonal function.

The process of obtaining complex information from the environment regardless of our awareness is called *implicit learning*; this is the mechanism that supervises, e.g., the learning of language [33]. Many studies show that preschool children have implicit knowledge of tonal harmony: they can recognize the best target chord in a tonal context [35] or identify a deviant musical chord in a tune accompaniment [9].

In the remainder of this section, we will introduce the most relevant aspects to take into account in order to implement an educational activity aiming at the development of harmony awareness.

2.1 Representation of the Harmonic Space

The first step of the process is to find a suitable representation of the harmonic space, limiting the chords to be represented to a meaningful subset. Following Riemann's theory of the tonal functions of chords [34], we divide the harmonic space of a given key into *primary* and *parallel* chords [25]. Each chord is constituted by three notes, all belonging to the natural grades of a major scale. The second note of the chord is one third above the root note, and the third note of the chord is a fifth above.

In Riemann's theory, there are three primary chords, called tonic (T), subdominant (SD), and dominant (D): they correspond to the major triads built on the first, fourth, and fifth grade of a major scale, respectively. In addition, there are three parallel chords, called parallel tonic (T_p), parallel subdominant (SD_p), and parallel dominant (D_p). They are located a minor third below the corresponding primary chords; consequently, they are the minor triads built on the sixth, second, and third grade of a major scale, respectively.

Chords can be placed along a circle with the primary chords in the lower part and the parallel chords in the upper part, just above their relatives (see Fig. 1). This abstract scheme, even if highly simplified with respect to all the possibilities offered by tonal harmony, can fit a number of popular songs as well as classic music harmonization patterns, which can be a good starting point for understanding harmonic functions. This spatial arrangement enhances the perceptual differences between the primary-chord zone (all major chords) and the parallel-chord zone (all minor chords), making it easier to associate the sound of chords with their position.

This spatial representation of chords allows an easy navigation of the harmonic space, and users can discover and easily remember the routes of harmonic progressions, as shown by the colored paths in Fig. 1.

2.2 Melody Harmonization

Melody harmonization represents one of the common tasks for musicians and amateurs. The cognitive aspects of melody harmonization can be linked to the recognition of implied harmony and the detection of the harmonic rhythm.

Concerning the former issue, the perception of implied harmony determines the detection of a best fitting chord sequence to harmonize a leading voice. Considering the pitches on the main beats of a melody, implied harmony is driven by their belonging to a given chord. Also if the chord is not played or the melody does not contain all chord components, listeners equally make inferences about the implied harmony [36]. But musical chords share also common pitches among them, especially when harmonies more complex than triads are involved. As a consequence, sometimes more than one implied harmony may be perceived by listeners and, even in the context of tonal harmony, more than one chord sequence can be used for the harmonization of the same melody.

Concerning harmonic rhythm, it can be defined as the time pattern formed by harmonic-changes occurrences. In the example of Fig. 2, each beat is represented by a white square with a thicker black line every four squares to indicate the musical meter. The chord symbols are positioned in the points where a harmonic change occurs, determining thus the harmonic rhythm [1, pp. 376–377]. It is important to note that harmonic rhythm does not always coincide with the beats nor with measures.

Starting from the auto-accompaniment function embedded in electronic keyboards [12, p. 125], many software tools have been developed for creating automated melody accompaniment, such as Band–in–a–Box[10] and Chordify[11] (see Fig. 2).

[10] https://www.pgmusic.com.
[11] https://chordify.net.

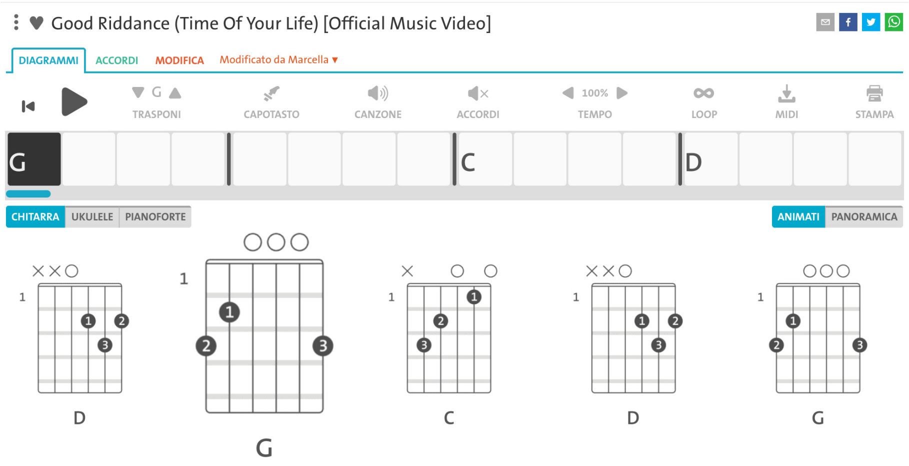


Fig. 2. A screenshot from Chordify website showing the diagram wiew of "Good Riddance" (Time Of Your Life) with the various functions in the upper bar.

2.3 Key Elements of Tonal Harmony Awareness

In Sect. 2.2 we have shown how the recognition of implied harmony and of harmonic rhythm are two cognitive aspects of melody harmonization. In the limits of this contribution we now define these same features as key elements of tonal harmony awareness and describe their relationship with the more basic elements of pitch and rhythm. Furthermore, we present metrics and analytic methods for automatically measuring users competence and progress in these domains within the context of already known methodologies for music performance analysis.

Traditional and contemporary assessment methods are based essentially on two domains: tonal (pitch, melody) and temporal (rhythm, rhythm to melody, accents, tempo), while more complex abilities such as harmony are supposed to build upon these basic elements [45]. Also other music aspects may be tested such as dynamics [22,37], timbre [37] and memory [30]; however, rhythm and pitch are the main pillars of music making. When combined together, they can produce complex and interesting musical patterns such as harmony, counterpoint and musical forms [20].

Following this assumption, implied harmony and harmonic rhythm can be considered organization structures at higher level with respect to the basic domains of pitch and rhythm [8,43]. Corrigall & Trainor [9] report that children develop sensitivity to key membership earlier than to harmony. This is due to the fact that key membership involves note-by-note comparison to key, whereas harmony involves more complex single note–chord comparison within the key. To extract harmonic information from melody, children need to direct attention on multiple aspect of a music excerpt (beat, pitch, melodic contour, etc.) [10].

Moreover, to decode the complex information conveyed by musical chords it is necessary to involve the capacity to simultaneously perceive numerous sounds as one whole, an ability defined as *harmonic hearing* by Teplov [42]. As far as concerns the perception of harmonic rhythm, a way to explain it is to refer to the hierarchical theory of musical meter by Lerdhal and Jackendoff [24] where rhythmic perception has a tree-like structure similar to that of Fig. 3. The first level reports the rhythm of pitch events, the second the *tactus*, the third the meter (4/4). The fourth level (harmonic rhythm) has been added to show the high level position of this feature.

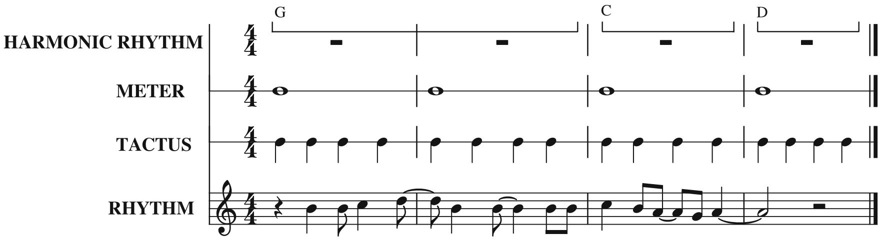


Fig. 3. Four levels of rhythm perception in "Good Riddance" (Time Of Your Life).

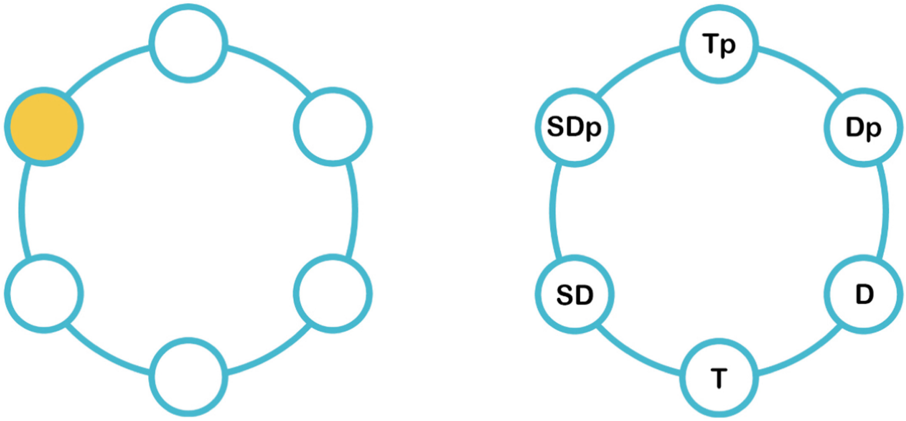
3 The Web Platform

Building on the previous discussion, this section presents a web platform that implements a series of experiences aimed at fostering and assessing tonal harmony awareness.

3.1 Methods for the Automated Assessment of Musical Abilities

Objectively assessing musical abilities is a much studied – and controversial – problem. Musical aptitude batteries proposed in the second half of 20$^{\text{th}}$ century are now considered obsolete in several respects [22]. The concept of musical ability is multifaceted and includes various types of musical capacity (e.g., tempo, pitch, rhythm, timbre, melody perception) that are not easily separated.

One of the domains where all these features converge is musical performance [4]. While it is relatively easy to assess users achievements in a computer assisted environment based on multiple choice tests, it is much more complex to assess a musical performance where multiple parameters must be tracked and evaluated, such as tempo and timing, dynamics, pitch and timbre [23]. Music information retrieval (MIR) offers a series of techniques useful to treat these problems, such as time-frequency representation, spectral decomposition, onset detection and note tracking [14]. Many educational systems are based on MIR methods,



(a) Recognition of implied harmony. (b) Melody harmonization.

Fig. 4. The circular representation of the harmonic space employed in the first and in the third experience of *Harmonic Touch* [25].

such as Smart Music[12] which provides immediate feedback to students' performances, Tonara[13] for interactive score-following, and MySong[14] for automatic accompaniment of vocal melodies. Objective descriptors of music performance may be score–dependent or score–independent. Score–dependent features represent performance accuracy with respect to pitch, dynamics and rhythm; score–independent information is extracted by aligning score data to the extracted features through dynamic time warping techniques[15] [44].

As far as the study of tonal harmony is concerned, various applications have been proposed in the literature with the aim of aiding the understanding of musical chords and harmonic progressions [7,17–19]. One notable example is *Mapping Tonal Harmony*, a tool for visualizing the various shifts through harmonic regions in real time.[16] However it must be noted that all these systems are rather complex to use and are not finalized for use in primary or middle schools.

3.2 Harmonic Touch

Harmonic Touch[17] is a publicly-available web platform conceived as a step-by-step wizard containing self-explanatory descriptions that lead users through a series of experiences towards the ultimate goal of melody harmonization.

[12] https://www.smartmusic.com.
[13] https://tonara.com.
[14] https://www.microsoft.com/en-us/research/project/mysong-automatic-accompaniment-vocal-melodies.
[15] Dynamic time warping is an algorithm for measuring similarity between two temporal sequences [28].
[16] https://mdecks.com/mapharmony.phtml.
[17] http://didacta18.lim.di.unimi.it/eng/.

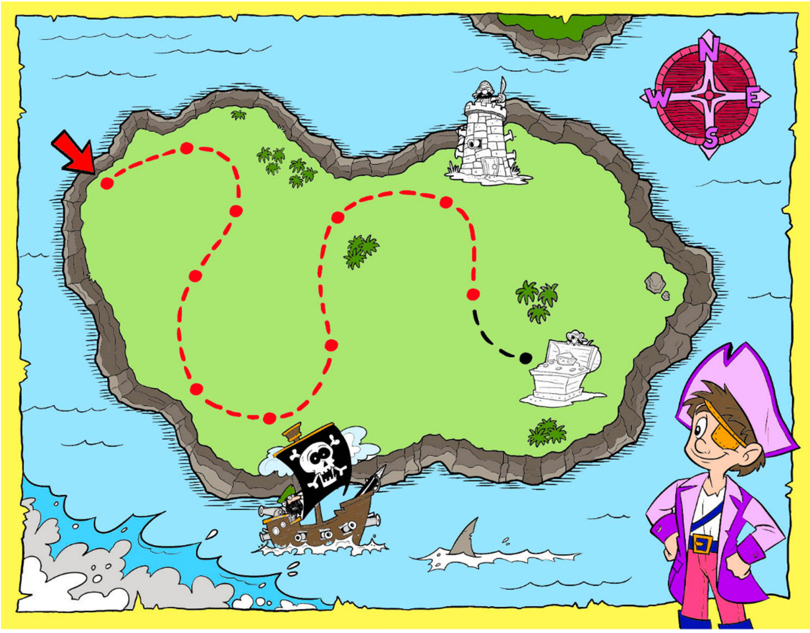


Fig. 5. The interface of the second experience: recognition of the harmonic rhythm [25].

Although the application is mainly concerned with theoretical music abilities rather than musical instrument performance, it shares some common traits with the works reviewed above, namely a performative dimension and a gamified approach.

Skipping the abstractions traditionally used to introduce this topic (keys, scales, intervals, chords, etc.), *Harmonic Touch* employs the perceived qualities of musical chords to engage learners in experiences designed on the basis of the fundamental features of tonal harmony described in Sect. 2. As discussed in Sect. 4, the data resulting from these experiences are an important basis for an *a posteriori* analysis of learners' performances, as they hold a significant amount of information about users perception, musical preference and attitudes.

Harmonic Touch presents three web-based experiences using a device attached to the internet. These activities aim at an intuitive and direct communication, do not depend on previously acquired theoretical knowledge, and utilize a gamified approach to introduce primary and middle school students to the subject of tonal harmonic awareness.

The three experiences, based on the cognitive aspects mentioned in Sect. 2, are the following:

1. *Recognition of Implied Harmony* – The learner is asked to match a brief music excerpt with a single chord that, in her view, best suits the whole melody. The chord is selected from the set of primary and parallel chords mentioned

above. Following the spatial schema explained in Sect. 2.1, in this experience the harmonic space is represented through the circle shown in Fig. 4(a), where the layout of chords is fixed, but the position of the tonic is randomly rotated and no chord label is visible. Understanding the relative position of chords is left to the user, who can explore them freely during the training phase.

2. *Recognition of Harmonic Changes (harmonic rhythm)* – In accordance with a gamification approach, the experience takes place over a sort of treasure map, or any other graphical representation of a step-by-step path. After carefully listening to a complete piece (melody and chords), the learner is asked to reconstruct it by moving one step ahead over the map whenever a new chord is expected. An example of interface is shown in Fig. 5. If the click does not occur at the right timing, music stops; if it is performed in advance, a part of the tune is skipped.
3. *Melody Harmonization* – This experience requires to select the right chords at the right timing in order to accompany a known music tune. Conceived as the natural evolution of the previous experiences, this one focuses on the simultaneous recognition of the best-fitting chords and the occurrence of harmonic changes. The graphical interface, shown in Fig. 4(b), recalls the circular representation of chords of the first experience, where the spatial relationship among chords is maintained; in this case, the position of the tonic is fixed and chord labels are explicitly indicated.

In the current implementation, each group of experiences starts with a training phase to make the user accustomed to the interface. After the training phase, three exercises per group of experiences are proposed.

The system tracks timing and sequences of mouse clicks and saves them into a database, so that single user performances and improvements can be assessed and typical cross-user behaviors can emerge.

4 Assessment of Harmonic Awareness

This section presents and discusses experimental data collected through the web platform during a workshop on music education and digital languages, at the 2nd edition of Didacta Italy, Florence, October 18–20, 2018.[18] The workshop aimed at involving music teachers in the use of the application, as well as analyzing teachers' performances and behaviors in the proposed experiences. It was attended by 45 middle (57%) and primary (25%) school teachers, with mean age = 49.8 (median = 51) and mean working age = 22.7 years (median = 20 years). The complete data set of results (answers to pre-activity and post-activity surveys, and the three experiences described in Sect. 3) is publicly available.[19]

The remainder of the section presents a behavioral analysis of the users involved in the experiences, with the aim of characterizing prototypical behaviors in using (and possibly misusing) the application. The goal is to assess the

[18] http://fieradidacta.indire.it/, the most important Italian fair focusing on education, vocational training and relation among school and work.

[19] http://didacta18.lim.di.unimi.it/results/index.html.

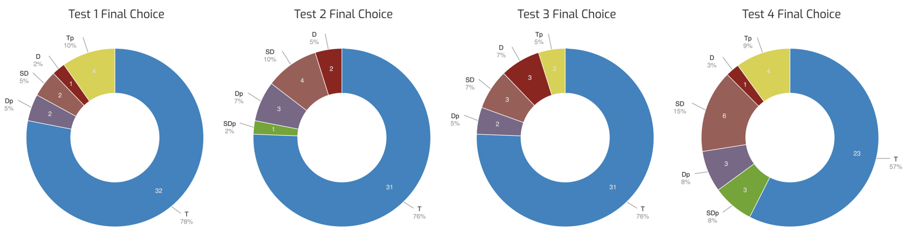


Fig. 6. Distribution of the chords selected at the end of each test.

Table 1. Minimum m, maximum M, mean μ, and standard deviation σ of selection time and number of explored chords.

	Selection time (s)				Explored chords ($\sharp$)			
	m	M	μ	σ	m	M	μ	σ
Test 1	0.55	211.65	65.01	49.38	0	22	5.78	5.49
Test 2	1.25	577.71	75.18	90.82	0	27	7.66	5.82
Test 3	1.03	185.91	38.43	38.32	0	18	4.73	4.53
Test 4	2.06	174.36	43.38	38.00	0	32	7.18	7.56

effectiveness of the proposed approach, and to develop a set of guidelines and tools that can help teachers evaluate pupils based on the experimental data gathered through the platform. An additional, long-term goal is to develop a set of quantitative metrics through which tests performed by users can be given objective scores (an early attempt was made [2], limited to Experience 1).

4.1 Experience 1: Implied Harmony

Four tests were administered in this experience, where the first one served as training. The corresponding music excerpts are: "Bolero" (Maurice Ravel), 8 measures; "Brother John" (traditional), 12 measures; "Guglielmo Tell" (Gioacchino Rossini), 16 measures of the Ouverture theme; "Tourdion" (traditional), 6 measures. These share the common characteristic that the implied harmony is a single tonic chord for the entire duration of the excerpt.

Figure 6 shows the distribution of chords selected by users at the end of each test. The majority of the users chose the tonic chord **T** for all tests, which seems to demonstrate harmonic awareness by most users. Note that the first three tests are all in major key and very popular, while Test 4 is in minor key and is a little known piece from French Renaissance. Accordingly, the distributions for the first three tests are very similar, with **T** chosen by about 80% of the participants, while those for Test 4 are markedly different, with **T** chosen by only 57% of users.

Table 1 illustrates some additional data aggregated across users, regarding the "selection time" and the number of explored chords for each test. The former

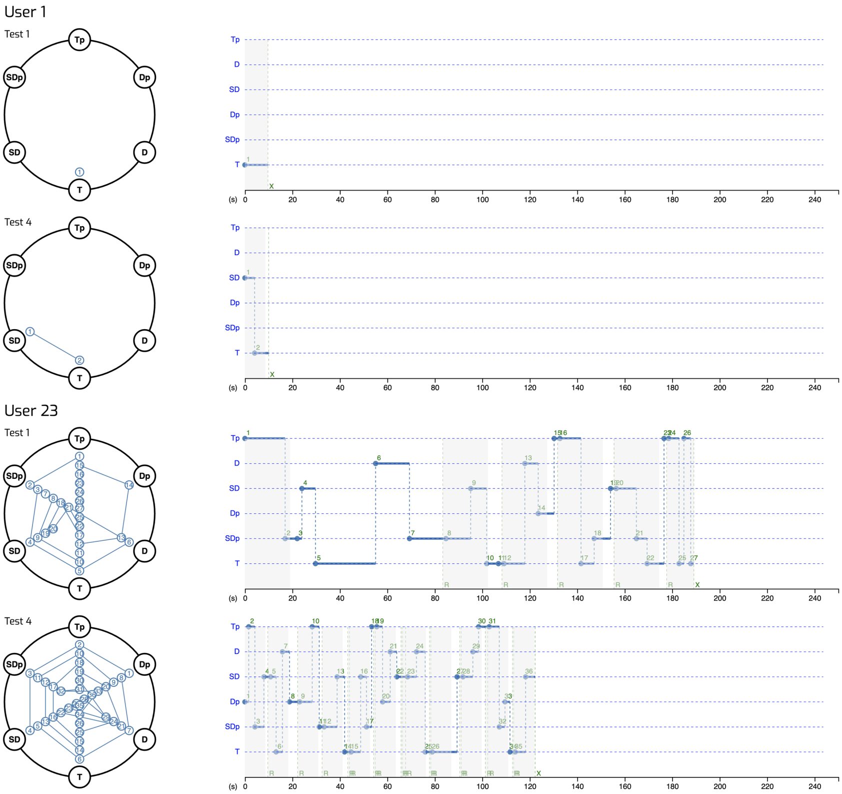


Fig. 7. Performance of two users in Experience 1. Left panels depict user trajectories on the harmonic space representation, while right panels show the same trajectories as functions of time; the order in which chords were clicked is represented by progressive integers. 'R' and 'X' labels on the time axis represent instants when the user restart the test or proceed to the next one, respectively. Shaded areas correspond to time segments where there is actual music playback.

quantity refers to the time elapsed between the instant when the selected chord is first clicked and the instant when the user confirms its selection. These data show a tendency towards an exploratory behavior by users, who continue navigating through chords even after clicking the one that they consider correct.

A comprehensive analysis of the results allowed to identify two prototypical behaviors: the "frantic explorer", who wanders around the circle, usually following a clockwise or counterclockwise path, possibly several times; and the "self-confident user", who stops almost immediately after choosing the expected chord.

Figure 7 shows two examples of these behaviors. User 1 exhibited self-confidence, jumped quickly to the selected chord in a few seconds and stopped. Conversely, User 23 showed a tendency to replicate an exploratory behavior over

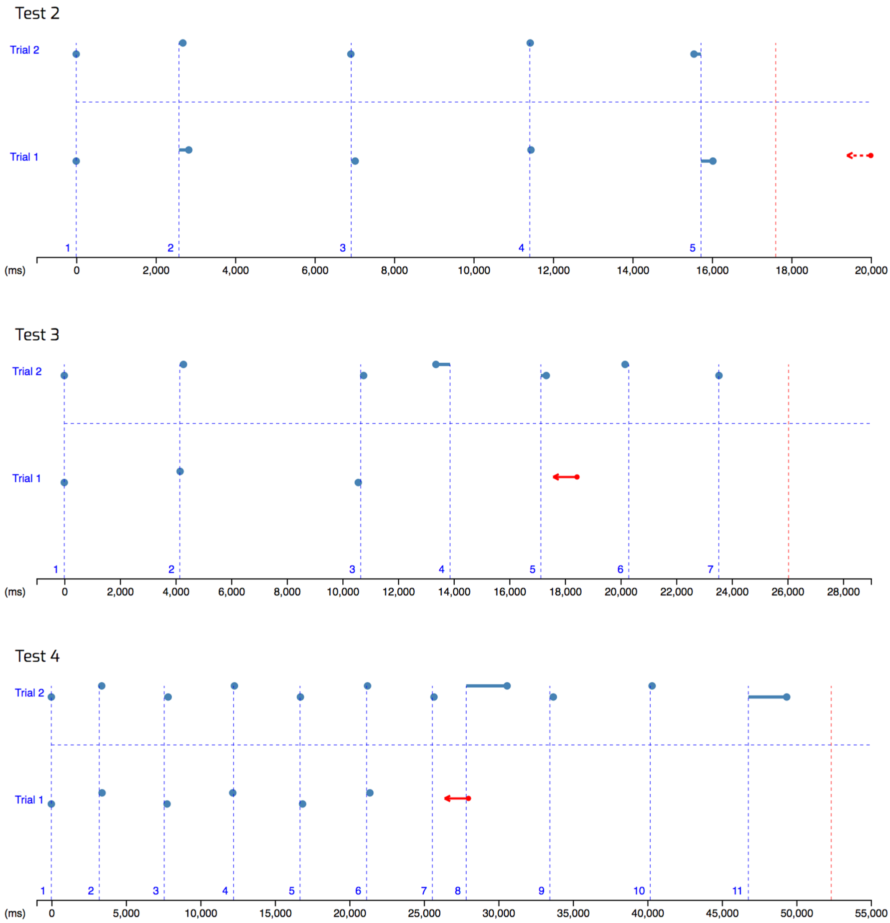


Fig. 8. Performance of User 12 in Experience 2 (the training test is excluded). The x-axis shows the song time, while the vertical dashed lines and the adjacent progressive numbers show instants of harmonic changes. Blue dots and horizontal segments show lag and lead errors by the user with respect to correct timing. Red dots and arrows show instants when the user started a new trial for the same test.

tests and trials. No evident learning effect was noticed: some users seemed to learn to stop at the first occurrence of the tonic chord, or to minimize the number of attempts after that, but not to jump towards the final destination with confidence. This is a confirmation that this experience stimulated a playful behavior by users rather than stimulating them to complete a task.

4.2 Experience 2: Harmonic Rhythm

Four tests were administered in this experience, where the first one served as training. The corresponding music excerpts are: "La donna è mobile" (*aria* from

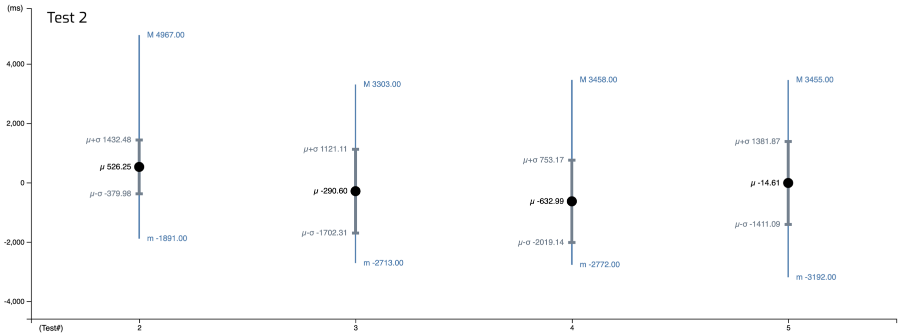


Fig. 9. Distribution of errors across all users in Experience 2.

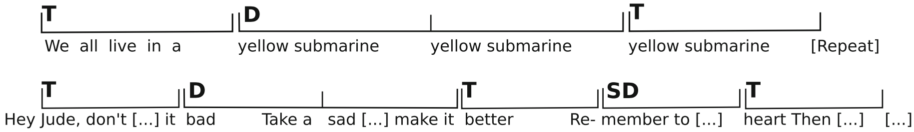


Fig. 10. Harmonic rhythm of Tests 2 and 3, Experience 2.

Giuseppe Verdi's "Rigoletto"), 16 measures with T-D changes; "Yellow Submarine" (The Beatles), 8 measures (refrain) with T-D changes; "Hey Jude" (The Beatles), 8 measures (first verse) with T-D-SD changes; "Il ragazzo della via Gluck" (Adriano Celentano), 18 measures (second verse) with T-D-Tp changes.

Overall, the performance across users was extremely varied. Qualitative analysis of the results shows that some users performed almost perfectly: this is a cue that the task was clearly explained and that the interface was usable. On the other hand, several users performed poorly and seemed to exhibit a limited awareness of harmonic rhythm. Figure 8 shows one of the most precise performances.

It is worth analyzing lag (negative) errors and lead (positive) errors separately. The error distribution across all users exhibits a clear asymmetry, with more lags with respect to leads. Two remarks can be made. First, lag errors are larger than lead errors: this can be expected, because users will typically click after having perceived a harmonic change, unless they are extremely confident (e.g., they know well the harmony of the music excerpt) and are thus able to anticipate a harmonic change. Second, lag errors are quite large and larger than lead errors. This instead is a counter-intuitive result: recall that the playback stops if no click occurs at the harmonic change. Therefore users would be expected to click as soon as the music stops, regardless of whether or not they have actually recognized a harmonic change.

Based on the above remark, it can be hypothesized that small lag errors are simply due to the reaction time of the user to the music stopping. Psychophysical studies provide a lower bound for auditory reaction times, which in experimental

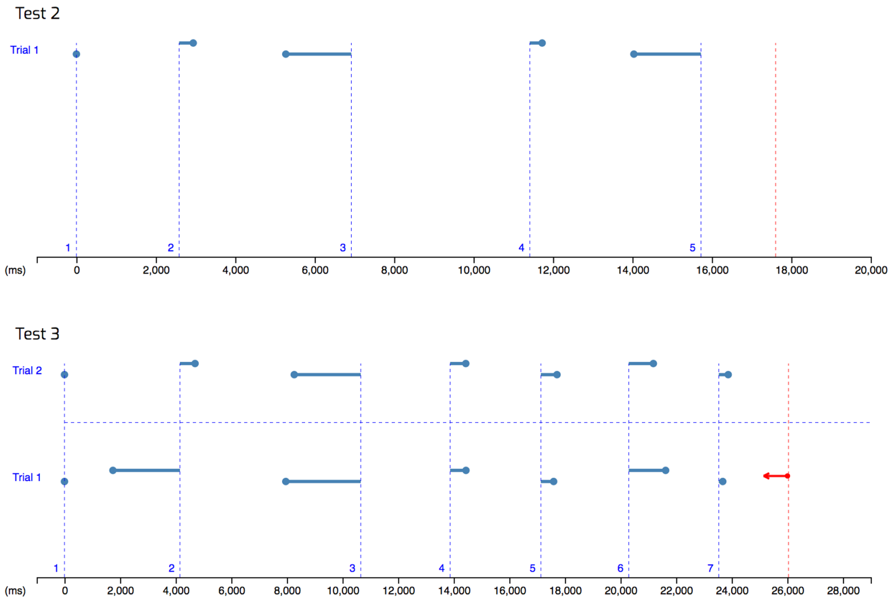


Fig. 11. Performance of User 5 in Experience 2 (Tests 2 and 3 only). Plots are organized as in Fig. 8.

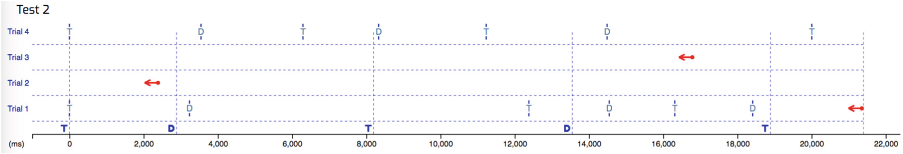
settings can be as low as 300 ms [39]. However, it is reasonable to assume that users' reaction times were much higher than this lower bound (e.g., between 500 ms and 1 s), as they were focusing on a different task. It can be assumed that only lag errors above a certain threshold related to the reaction time are actually significant, since they are due to the user not expecting an harmonic change and thus not being prepared to click at the right time. On the other hand, errors smaller than this threshold can be attributed to the reaction time of the user to the music stopping.

Lead errors are more interesting, as they provide more insight on the actual user awareness of harmonic rhythm. Specifically, large leads are a signal of the user having misplaced a harmonic change. Examples of this type of mistakes in harmonic rhythm recognition are particularly evident in Tests 2 and 3. In both cases the harmonic rhythm has some variations, with some changes occurring after one measure and some after two measures (see Fig. 10).

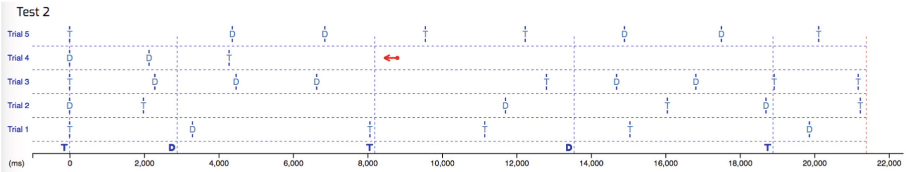
Several users were tricked by these structures, and had the tendency to incorrectly place all harmonic changes after one measure. Figure 11 shows a prototypical example of this behavior.

4.3 Experience 3: Melody Harmonization

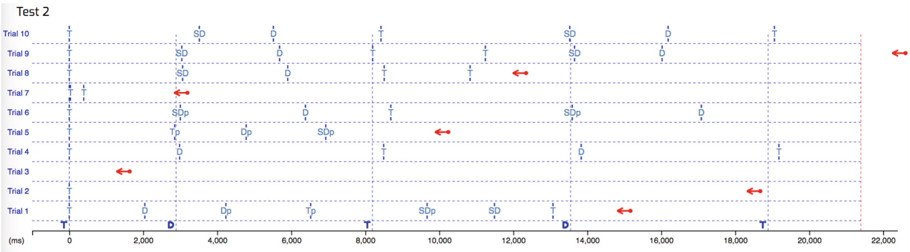
Four tests were administered in this experience, where the first one served as training. The corresponding music excerpts were the same as in Experience 2.



(a) User 2



(b) User 21



(c) User 19

Fig. 12. Performance of three users in Experience 3 (Test 2). The x-axis shows the song time, while the vertical dashed lines and the adjacent letters (bottom) show instants of harmonic changes and the corresponding chords. The remaining letters show chords selected by the user at a certain time instant. Red dots and arrows show instants when the user started a new trial for the same test.

This ensured that users were already familiar with the musical and harmonic materials. Users could listen to the melodic line of each excerpt and had to harmonize it. The last two tests were swapped with respect to Experience 2, thus in this experience Test 3 was "Il ragazzo della via Gluck" (Adriano Celentano) while Test 4 was "Hey Jude" (The Beatles).

As explained earlier, melody harmonization requires to simultaneously recognize the occurrence of harmonic changes and the correct chord at each harmonic change, where "correct" here means the one of the original song. Other chord sequences may be found that also fit the melody. Whether to consider or not this as a mistake is debatable and may be left at the teacher's evaluation.

As a consequence, Experience 3 was expected to be the most challenging one for the users. An analysis of the number of trials performed by each user for each test confirmed this hypothesis. At several instances, users performed 20 trials or more of a single test. There was one case (User 23, Test 2) in which 48 trials were performed, for a total time of approximately 8 minutes spent on the same

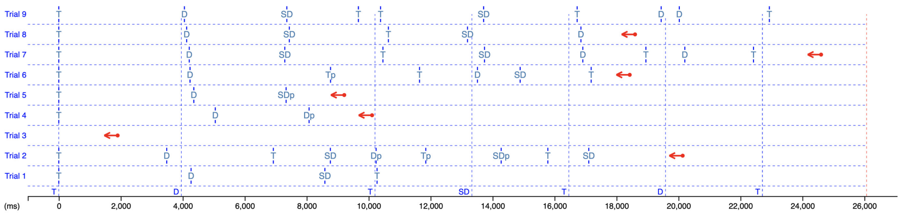


Fig. 13. Performance of User 5 in Experience 3 (Test 4). Plots are organized as in Fig. 12.

test. This behavior is markedly different from that observed in the preceding experiences, and also suggests that Experience 3 was the most engaging one.

Given the complexity of the task, the sources of error are more numerous and a wider spectrum of behaviors by the users was observed. Figure 12 shows relevant examples of the behavior of three different users on Test 2 ("Yellow Submarine"). The top panel (User 2) provides an example of wrong harmonization, in which the user anticipated the harmonic changes and separated them by one measure (at about 6.5 s and 11.5 s along the song time) instead of two measures: this can be explained by looking back at Fig. 10 and the related discussion. The second panel shows instead a case (User 21) in which the same chords were selected twice consecutively: this cannot be considered a mistake in the harmonization (although the temporal accuracy is low). Finally, the bottom panel shows yet another different behavior (User 19) in which the harmonic progression **T-SD-D-T** was used consistently and with good temporal accuracy in place of the correct progression **T-D-T**: this is an interesting case in which the user's choice is plausible and compatible with respect to the melodic line.

One further example, partially related to the latter one, is provided in Fig. 13, which shows the performance of one user on Test 4 ("Hey Jude"). The user consistently inserted a harmonic change after one measure (at about 7 s along the song time). This has to be considered as a mistake, however it has to be noted that a subtle change actually occurs in the song at that particular point: namely, the triad on the dominant changes into a quadriad (a "seventh" chord with an added note with respect to the triad), while remaining on the dominant. Therefore, although the harmonic function (**D**) is not changing, the chord sounds different. In fact, other users exhibited a similar behavior at this particular point of Test 4.

5 Discussion and Conclusions

The analysis of experimental data presented in the previous section triggers several points of discussion.

First, the choice of the music materials is critical. The excerpts should be sufficiently simple harmony-wise, ideally composed by triads only. At the same time, they should be already known to all the users in order to build on their implicit knowledge of tonal harmony. These two requirements pose severe constraints on the usable repertoire. In order to let the teachers additional freedom in choosing their own repertoire, we plan to extend the platform with authoring tools that allow to upload new music pieces, to segment them according to their harmonic rhythm, to augment them with metadata related to chords and relative timings, and so on. This would also allow teachers to customize contents and to adapt them to their educational goals, e.g. to develop learning paths focused on specific genres or composers.

Another major point of discussion is concerned with the evaluation of user performances. The above analysis shows that this is a multidimensional problem which includes objective measures such as timing of harmonic changes and chord correctness, but also contextual elements such as user reaction times, alternative correct harmonizations, and so on. As a consequence, the task at hand cannot always be evaluated through a binary correct/wrong decision, and some subjective evaluation by the teacher may be required. This calls for the development of graphical representations of the users' performances, which display relevant elements and aid the teachers in their evaluations by taking into account different behaviors, sources of errors, and any additional contextual information. The visualizations reported in this paper are a first example of possible graphical representations aimed at this use.

Finally, the data analyzed in this paper represent a preliminary test of the platform, with a group that is not representative of the final users (upper elementary or middle school pupils). We are currently planning an experimental campaign in collaboration with primary and middle school music teachers, in which a class will be exposed to tonal harmony activities involving the use of the web platform for several months. Learning results will be compared to a second class which will serve as a control group.

References

1. Apel, W.: The Harvard Dictionary of Music. Harvard University Press, Cambridge (2003)
2. Avanzini, F., Ludovico, L.A., Baratè, A., Mandanici, M.: Metrics for the automatic assessment of music harmony awareness in children. In: Proceedings International Conference Sound and Music Computing (SMC2019), pp. 372–379. Malaga, May 2019
3. Beckstead, D.: Will technology transform music education? Music Educ. J. **87**(6), 44–49 (2001)
4. Brandao, M., Wiggins, G., Pain, H.: Computers in music education. In: Proceedings of the AISB 1999 Symposium on Musical Creativity, pp. 82–88 (1999)
5. Brown, A., Brown, A.R.: Computers in Music Education: Amplifying Musicality. Routledge (2012)
6. Butler, D., Brown, H.: Describing the Mental Representation of Tonality in Music. Oxford University Press, Oxford (1994)
7. Chew, E., Francois, A.R.: Interactive multi-scale visualizations of tonal evolution in MuSA. RT Opus 2. Comput. Entertain. **3**(4), 1–16 (2005)

8. Cohrdes, C., Grolig, L., Schroeder, S.: Relating language and music skills in young children: a first approach to systemize and compare distinct competencies on different levels. Front. Psychol. **7**, 1616 (2016)
9. Corrigall, K., Trainor, L.: Effects of musical training on key and harmony perception. Ann. N. Y. Acad. Sci. **1169**(1), 164–168 (2009)
10. Costa-Giomi, E.: Young children's harmonic perception. Ann. N. Y. Acad. Sci. **999**(1), 477–484 (2003)
11. Crawford, R.: Rethinking teaching and learning pedagogy for education in the twenty-first century: blended learning in music education. Music Educ. Res. **19**(2), 195–213 (2017)
12. Crow, B.: Music-related ICT in education. In: Learning to Teach Music in the Secondary School, pp. 130–153. Routledge (2005)
13. Csapó, B., Ainley, J., Bennett, R.E., Latour, T., Law, N.: Technological issues for computer-based assessment. In: Griffin, P., McGaw, B., Care, E. (eds.) Assessment and Teaching of 21st Century Skills, pp. 143–230. Springer, Dordrecht (2012). https://doi.org/10.1007/978-94-007-2324-5_4
14. Dittmar, C., Cano, E., Abeßer, J., Grollmisch, S.: Music information retrieval meets music education. In: Dagstuhl Follow-Ups. vol. 3. Schloss Dagstuhl-Leibniz-Zentrum fuer Informatik (2012)
15. European Commission: Digital learning & ICT in education (2019). https://ec.europa.eu/digital-single-market/en/policies/digital-learning-ict-education
16. Folkestad, G.: Formal and informal learning situations or practices vs formal and informal ways of learning. Br. J. Music Educ. **23**(2), 135–145 (2006)
17. Hedges, T.W., McPherson, A.P.: 3D gestural interaction with harmonic pitch space. In: Proceedings of the International Computer Music Conference and Sound and Music Computing Conference (ICMC-SMC 2013), pp. 103–108 (2013)
18. Holland, S.: Learning about harmony with harmony space: an overview. In: Smith, M., Smaill, A., Wiggins, G.A. (eds.) Music Education: An Artificial Intelligence Approach, pp. 24–40. Springer, London (1994). https://doi.org/10.1007/978-1-4471-3571-5_2
19. Johnson, D., Manaris, B., Vassilandonakis, Y.: Harmonic navigator: an innovative, gesture-driven user interface for exploring harmonic spaces in musical corpora. In: Kurosu, M. (ed.) HCI 2014. LNCS, vol. 8511, pp. 58–68. Springer, Cham (2014). https://doi.org/10.1007/978-3-319-07230-2_6
20. Krumhansl, C.L.: Rhythm and pitch in music cognition. Psychol. Bull. **126**(1), 159 (2000)
21. Laitz, S.G.: The Complete Musician: An Integrated Approach to Tonal Theory, Analysis, and Listening. Oxford University Press, Oxford (2015)
22. Law, L.N., Zentner, M.: Assessing musical abilities objectively: construction and validation of the profile of music perception skills. PLoS ONE **7**(12), e52508 (2012)
23. Lerch, A., Arthur, C., Pati, A., Gururani, S.: Music performance analysis: a survey. In: Proceedings of the International Society for Music Information Retrieval Conference (ISMIR), Delft, 2019 (2019)
24. Lerdahl, F., Jackendoff, R.S.: A Generative Theory of Tonal Music. MIT press, Cambridge (1996)
25. Mandanici, M., Ludovico, L., Avanzini, F., et al.: A computer-based approach to teach tonal harmony to young students. In: International Conference on Computer Supported Education, pp. 271–279. SCITEPRESS (2019)
26. Mishra, P., Koehler, M.J.: Technological pedagogical content knowledge: a framework for teacher knowledge. Teach. Coll. Record **108**(6), 1017–1054 (2006)

27. MIUR: Piano nazionale scuola digitale (2015). https://www.miur.gov.it/scuola-digitale
28. Müller, M., Mattes, H., Kurth, F.: An efficient multiscale approach to audio synchronization. In: ISMIR, vol. 546, pp. 192–197. Citeseer (2006)
29. Papert, S.: Mindstorms: Children, Computers, and Powerful Ideas. Basic Books Inc. (1980)
30. Peretz, I., Champod, A.S., Hyde, K.: Varieties of musical disorders: the montreal battery of evaluation of amusia. Ann. N. Y. Acad. Sci. **999**(1), 58–75 (2003)
31. Piaget, J.: The Origins of Intelligence in Children. International Universities Press, New York (1952)
32. Rameau, J.P.: Traité de l'harmonie reduite à ses principes naturels: divisé en quatre livres. Ballard (1722)
33. Reber, A.S.: Implicit learning and tacit knowledge. J. Exp. Psychol. Gen. **118**(3), 219 (1989)
34. Riemann, H.: Harmony Simplified, or the Theory of the Tonal Functions of Chords. Augener Ltd. (1896)
35. Schellenberg, E.G., Bigand, E., Poulin-Charronnat, B., Garnier, C., Stevens, C.: Children's implicit knowledge of harmony in western music. Dev. Sci. **8**(6), 551–566 (2005)
36. Schenker, H.: Free Composition: Volume III of New Musical Theories and Fantasies, vol. 1. Pendragon Press (2001)
37. Seashore, C.E., Lewis, D., Saetveit, J.G.: Seashore Measures of Musical Talents. Psychological Corp. (1956)
38. Sephus, N.H., Olubanjo, T.O., Anderson, D.V.: Enhancing online music lessons with applications in automating self-learning tutorials and performance assessment. In: 2013 12th International Conference on Machine Learning and Applications, vol. 2, pp. 568–571. IEEE (2013)
39. Shelton, J., Kumar, G.P.: Comparison between auditory and visual simple reaction times. Neurosci. Med. **1**(1), 30–32 (2010)
40. Shute, V.J., Ke, F.: Games, learning, and assessment. In: Ifenthaler, D., Eseryel, D., Ge, X. (eds.) Assessment in Game-Based Learning, pp. 43–58. Springer, New York (2012). https://doi.org/10.1007/978-1-4614-3546-4_4
41. Stevens, R.: Editorial. Res. Stud. Music Educ. **3**(1), 1–2 (1994). https://doi.org/10.1177/1321103X9400300101
42. Teplov, B.: Psychology of music and musical abilities. Leningrad: Izdatelstvo Pedagogicheskih Nauk (in Russian), Moscow (1947)
43. Trehub, S.E., Hannon, E.E.: Infant music perception: domain-general or domain-specific mechanisms? Cognition **100**(1), 73–99 (2006)
44. Vidwans, A., Gururani, S., Wu, C.W., Subramanian, V., Swaminathan, R.V., Lerch, A.: Objective descriptors for the assessment of student music performances. In: Audio Engineering Society Conference: 2017 AES International Conference on Semantic Audio. Audio Engineering Society (2017)
45. Wallentin, M., Nielsen, A.H., Friis-Olivarius, M., Vuust, C., Vuust, P.: The musical ear test, a new reliable test for measuring musical competence. Learn. Individ. Differ. **20**(3), 188–196 (2010)
46. Walls, K.C.: Music performance and learning: the impact of digital technology. Psychomusicol.: J. Res. Music Cogn. **16**(1–2), 68 (1997)
47. Webster, P.R.: Construction of music learning. MENC Handb. Res. Music Learn. **1**, 35–83 (2011)
48. Zagami, J., et al.: Creating future ready information technology policy for national education systems. Technol. Knowl. Learn. **23**(3), 495–506 (2018)