The CrazySquare Project: A Technological Pedagogical Content Knowledge Solution

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Abstract: The aim of this paper is to present the current status of the CrazySquare project, a research and development project aiming at realizing an ICT support system for playing guitar within Italian middle schools. The CrazySquare project follows an iterative process based on the TEL-oriented UCD approach. Currently, we are designing the user-based evaluation of the second iteration. Differently from the first iteration, which produced a prototype aimed at digitalizing the paper and pencil CrazySquare procedure, the current iteration aims at developing an ICT learning tool including some gamification elements, such as rewards, points, levels, and immediate feedback.

1 INTRODUCTION

"*Music is a universal language of mankind*" (Longfellow, 1857). Across different cultures, music is a transversal concept; everybody in the world listens to music every single day. Music education deals with three specific learning domains: the psychomotor domain, the cognitive domain, and the affective domain (Pearce and Rohrmeier, 2012). In particular, musical learning (musical education and learning to play musical instruments) enhances a wide range of cognitive and affective functions, such as language and social cognition (Pearce and Rohrmeier, 2012; Miendlarzewska and Trost, 2014). For this reason, playing musical instruments improves the cognitive skills. Nevertheless, learning to play musical instruments is not an intuitive and automatic task; in fact, many people consider this a challenging task that requires a lot of time and adequate guidance (Hallam and Creech, 2010; Miendlarzewska and Trost, 2014). Indeed, these issues are also highlighted by the Decree Law no. 201/99 that organized the musical activities in Italian Middle School (Decree law no. 201, 1999). The decree explicitly describes the musical education skills that students should achieve at the end of Middle School (melody, harmony, rhythm, timbre, dynamic, agogic, and instrumental skills). Furthermore, the adequately controlled adoption of tools made available by modern technologies is defined to be methodologically effective. Although the (Decree Law no 201, 1999) points out that one of the main objectives of musical education is to guarantee musical literacy and the internalisation of sounds, (1) no specific guidelines are provided in terms of which pedagogical approaches and technological tools should be applied to achieve the cognitive and instrumental skills and (2) no specific guidelines on the technological tools could be used to achieve these skills.

Based on these premises, this study aims at presenting an ICT learning tool, namely CrazySquare, for playing the guitar in Italian educational system, with a game-based approach. CrazySquare is dedicated to the guitar since it is one of the most popular musical instrument in Middle Schools. To provide a "way" to effectively integrate the technology into teaching activities, the CrazySquare project is underpinned by the TPACK (Technological Pedagogical Content Knowledge) framework, a model of technology-based instruction proposed by (Mishra and Koehler, 2006). It is a cornerstone, quoted in Google Scholar almost 9180 times. According to this framework (see Figure 1), primary forms of knowledge are:

- **Content Knowledge (CK):** all cognitive and instrumentals skills described by (Decree law no. 201, 1999);

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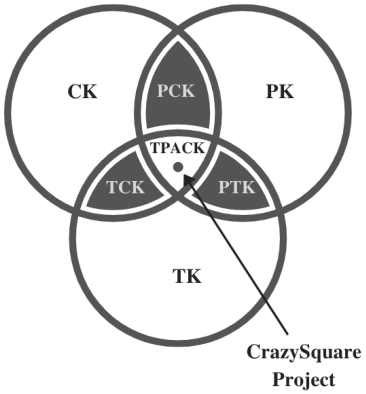


Figure 1: TPACK Framework.

- **Pedagogical Knowledge (PK):** e.g. constructivism and learning by doing approaches used in the traditional education setting (Koehler and Mishra, 2008);
- **Technological Knowledge (TK):** all digital tools available to teachers.

Intersecting these primary forms, secondary forms derive: PCK, TCK, and PTK. We focus on:

- **Pedagogical Content Knowledge (PCK):** among several pedagogical theories to musical education, the Musical Learning Theory (MLT) by Gordon (2007) is the theory that gives most importance to the internalisation of sounds, through *audiation* (musical thinking). Moreover, it is among the most established theories for music education, used both for very young children and pre-adolescents;
- **Technological Content Knowledge (TCK):** it refers to all ICT solutions for music education. As mentioned, we focus on guitar-oriented solutions given the specific context of use discussed later on.

In turn, intersecting TCK, PTK, and PCK, the TPACK form appears:

- **Technological Pedagogical Content Knowledge (TPACK):** from an analysis of currently available ICT-tools for music education, it seems that none of them could be framed in this space. Indeed, they do not clearly refer to a well-defined and valid musical pedagogical theory and to the concept of internalisation of sounds. More details about the analysis of existing tools in this field of education can be found in (Di Mascio et al., 2020).

The CrazySquare project goes in this direction, by proposing an innovative ICT tool inspired by Gordon's MLT which could fill *de facto* the TPACK space.

This paper is structured as follows: the pedagogical and methodological underpinnings are presented in Section 2, while in Section 3, the CrazySquare procedure is outlined and specified; in Section 4 the current status of the CrazySquare project is presented, while in Section 5 conclusion and future works are described.

2 PEDAGOGICAL AND METHODOLOGICAL UNDERPINNINGS

This section aims at describing the pedagogical and methodological underpinnings of CrazySquare; the key foundations of the Gordon's Music Learning Theory, in Subsection 2.1, inspiring the teaching activities of CrazySquare; the TEL-oriented UCD design approach that guarantees the compliance of CrazySquare as an ICT learning tool with Gordon's MLT, in Subsection 2.2.

2.1 Gordon's Music Learning Theory: Key Foundations

The core of Gordon's MLT is the *Audiation*, that *"takes place when we hear and comprehend music for which the sound is no longer or may never have been present. One may audiate when listening to music, performing from notation, playing «by ear», improvising, composing, or notating music"* (Gordon, 2007). The "audiation theory" is composed of eight types of audiation (e.g., "listening to", "reading", etc.). The conceptual basis of any type of *audiation* is that musical thought and language should develop in parallel (Gordon, 2007; Schellenberg, 2019). Underlying this concept are Gordon's ideas of *musical aptitude* and *musical achievement*. The author highlights the distinction between them, where the former represents one's potential to learn to audiate, whereas the latter represents, among other things, what one has learnt to audiate. CrazySquare project mirrors these two concepts. In this study, we referred to the Gordon's MLT *formal education* that is indicated for the teaching of music at school age, since the target users of CrazySquare are pre-adolescents (11-14). The formal education has the goal to achieve internalisation of sounds (*audiation*) first and then musical literacy; once the students have developed audiation skills, they acquire musical literacy, as also underlined by (Decree law no. 201, 1999). To achieve these objectives, Gordon proposes a method that is structured into two main stages of learning through

which students' individual progress is assessed. The stages are (1) *discriminatory learning* and (2) *inference learning*. Discriminatory learning is the ability to determine whether two elements are the same or not based on direct guidance by the teacher. While in inference learning, students take an active role in their own education and learn to identify, create, and improvise unfamiliar patterns. These stages are interrelated and each adds complexity to its associated task (Dorfman, 2013). Indeed, for each main stage of learning, Gordon (Gordon, 2007) describes tasks defined *stepwise movements* that are listed in Figure 2.

The Gordon MLT has been chosen as the so mentioned PCK, since it is based on the audiation that is *de facto* the internalisation of sounds defined in (Decree law no. 201, 1999). According to Gordon MLT, the achievement of the audiation is obtained through the formal education and according to (Decree law no. 201, 1999) the internalisation of sounds is achieved by acquiring both cognitive skills and instrumental skills. This mapping has been reported in Figure 2. Our choice comes from the fullness of the table. Note that empty spaces of table can be fulfilled through the "bridging" back and forth between stepwise movements, yet defined in the Gordon MLT.

2.2 TEL-oriented UCD

The CrazySquare project follows an iterative process based on the TEL-oriented UCD approach (see Figure 3) (Di Mascio et al., 2016). This methodology expands the traditional iterative user-centred design approach to emphasise the necessity of designing in parallel both a psycho-pedagogical stimulation plan and the system modules realising it in a context of mutual dependency, along with the choice of a psycho-pedagogical assessment strategy. Given its nature, following this design methodology enables to design an effective ICT learning tool compliant with the pedagogical underpinnings described above.

Indeed, jointly to the identification of needs, (Di Mascio et al., 2016) puts the *identification of learners*; jointly to specification of the context of use, puts the *identification and specification of psycho-pedagogical assessment strategy*; jointly to the specification of requirements, puts the *definition of the psycho-pedagogical plan*; jointly to the evaluation of the prototyping solution, puts the *evaluation of the psycho-pedagogical solution*; jointly to the realisation of the system solution, puts the *realisation of psycho-pedagogical solution*. The step related to the design of prototyping solution has not been changed.

3 CrazySquare AS TPACK SOLUTION

As mentioned, students have to achieve cognitive and instrumental skills. CrazySquare proposes to gain them by acquiring four main skills (from now denoted as A, B, C, D). These skills are defined as follows:

- **A.** Perceive and maintain the pulsation for predefined *Beats Per Minute* (BPM) value;
- **B.** Recognize and execute by reading a sequence of rhythmic symbols;
- **C.** Play with the instrument musical notes, articulating them through a reading of rhythmic symbols;
- **D.** Execute a change of musical note at different speeds.

In particular, A, B, C, and D are achieved by acquiring competencies of two levels of difficulty (base and advanced), from now on denoted by I and II. The description of each competency is reported in the 4^{th} row of Figure 4.

Since the chosen PCK is the Gordon MLT, CrazySquare proposes to achieve A, B, C, and D by performing stepwise movements, as reported in Figure 4. For example, the activities related to the competency B^I refers to several stepwise movements provided by both learning stages (e.g., partial synthesis and theoretical understanding).

Moreover, it is worth pointing out that there is a mutual dependency between skills and competencies, i.e. it is impossible to teach a skill without some competency of another skill. In the specific, the linear learning path through competencies is A^I, A^{II}, B^I, C^I, D^I, B^{II}, C^{II}, D^{II}.

At this stage of the project, CrazySquare mirrors some stepwise movements of Gordon's learning stages, as shown in Figure 4. At the end of TEL-oriented UCD process, all stepwise movements will be covered.

4 THE CrazySquare PROJECT

In this section, we present the current status of the CrazySquare project; the section is structured according to main steps of the TEL-oriented UCD schema.

4.1 Identifying Learners and Their Needs

The CrazySquare project addresses pre-adolescents (11-14 years old) who generally approach music and

				D.M. n.201/99									
				Internalisation of sounds									
	MLT formal education			Cognitive Skills						Instrumental skills			
	Learning Stages	Stepwise movements		Melody	Harmony	Rhythm	Timbre	Dynamic	Agogic	Sign-gesture-sound correlation	Execution and listening	Mastering of musical instrument	Musical improvisation
Audiation	Discrimination Learning	Aural/oral		x	x	x	x	x	x	x		x	
		Verbal association		x	x	x	x	x	x	x		x	
		Partial synthesis		x	x	x	x	x	x	x	x	x	x
		Symbolic association		x	x	x	x	x	x	x			
		Composite synthesis		x	x	x	x	x	x	x	x	x	x
	Inference Learning	Generalization	Aural/oral learning	x	x	x	x	x	x	x	x	x	
			Verbal learning	x	x	x	x	x	x	x	x	x	
			Symbolic reading	x	x	x		x		x	x	x	
			Symbolic writing	x	x	x				x			x
		Creativity/ improvisation	Aural/oral level	x	x	x	x		x	x	x	x	x
			Symbolic reading	x	x	x				x	x	x	x
			Symbolic writing	x	x					x			x
		Theoretical understanding		x	x	x	x	x	x		x	x	x

Figure 2: Mapping between Gordon's MLT formal education and learning objectives depicted by the Decree Law (Decree law no. 201, 1999).

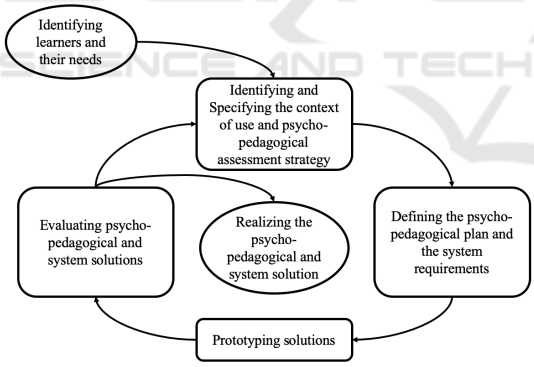


Figure 3: The TEL-oriented UCD schema.

guitar simultaneously for the first time and in a professional way since this is the age of students attending Middle School. According to (Decree law no. 201, 1999), the main need of the above mentioned students is to acquire musical literacy through the internalisation of sounds, as described extensively in Subsection 2.1. Moreover, there is the need to support learners in this challenging learning practice in order to keep their interest and motivation high, especially in the early stages. Indeed, the first months of learning are the most difficult, given the lack of knowledge of music theory. Therefore students often feel discouraged and bored, because they would immediately start playing the musical instrument. From an investigation of literature, it emerges that different strategies are addressing this issue all sharing the incorporation of certain concepts typical of video games, thanks to such as the video game medium, the motivation of players and their deep engagement while playing (Denis and Jouvelot, 2005). Consequently, the adoption of a gamified approach seems to be a successful choice to increase motivation in learners, performance and aptitude toward the course (Margoudi et al., 2016).

We have summarised these learners' needs as follows: (1) Acquisition of musical literacy, (2) Gamified learning experience, and (3) Adaptive and motivating learning path.

Moreover, it is worth pointing out that they are underaged learners who belong to the generation of digital natives; we have to meet their needs, aptitudes, and preferences. They use technology as a natural and easy concept; recent statistical data collected by ISTAT[1] in Italy confirm this (ISTAT, 2018). For example, in 2018, the 85.8% of people aged between 11-17 used a mobile phone daily, the 72% of people in the same age group surf the Internet every day

[1] ISTAT - Italian National Institute of Statistics

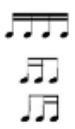
				CrazySquare							
				A		B		C		D	
MLT formal education				A^{I}	A^{II}	B^{I}	B^{II}	C^{I}	C^{II}	D^{I}	D^{II}
	Learning Stages	Stepwise movements		70 - 75 - 65 BPM	80 - 55 BPM			MI, FA, SI, DO, SOL, LA	SOL*, RE	Change of musical note each 2/4	Change of musical note each 1/4
Audiation	Discrimination Learning	Aural/oral									
		Verbal association									
		Partial synthesis				x	x				
		Symbolic association				x	x	x	x	x	x
		Composite synthesis									
	Inference Learning	Generalization	Aural/oral learning								
			Verbal learning			x	x				
			Symbolic reading			x	x	x	x	x	x
			Symbolic writing								
		Creativity/ improvisation	Aural/oral level								
			Symbolic reading			x	x	x	x	x	x
			Symbolic writing								
		Theoretical understanding		x	x	x	x	x	x	x	x

Figure 4: Mapping between Gordon's MLT formal education and CrazySquare.

and Internet access is strongly driven by the spread of smartphones. Furthermore, given their age, there is a need to ensure full compliance with normative on information society services to users and their relatives, namely the article 8 of General Data Protection Regulation "*Conditions applicable to child's consent in relation to information society services*" (EU-GDPR – Art. 8, 2016).

4.2 Identifying and Specifying the Context of Use and the Psycho-pedagogical Assessment Strategy

The learners could interact with CrazySquare ICT learning tool in two main environments: in the classroom, as a support during the teaching activities, and at home, as a support of homework activities. Both planned environments are indoor; we suggest that they should be free of distractions and loud noises, to facilitate learners' concentration and, consequently, the full accomplishment of assigned tasks.

As to the psycho-pedagogical assessment strategy, CrazySquare is grounded on gamification ideas of learning through gaming, training via iteration and rewarding structures to foster learning. Each learning experience consists of a series of gamified learning exercises, mirroring the two main concepts of music aptitude and music achievements as introduced by Gordon in (Gordon, 1989). In particular, the level of musical aptitude is a crucial concept that should be taken into account; students with low music aptitude should not become frustrated by the difficulty of the proposed exercises, whereas students with high music aptitude should not become bored by the simplicity of the proposed exercises. Consequently, with adherence to the CrazySquare procedure, we have defined a gamified Musical Skill Learning Model that should hence be capable of embedding the key foundations of Gordon's MLT, namely **MuS-LM.** More details about this model and its design process can be found in (Di Mascio et al., 2020). MuS-LM is grounded on the following general founding principle: *Students have to achieve musical skills including competencies through learning paths composed of "experience blocks" of homogeneous exercises according to their musical aptitude and achievement*. Indeed, each competency has its *practice space* made by one or more experience blocks including *mandatory* and *optional* sub-blocks; each of these represents a set of exercises (i.e.learning and relaxing mini-games) which are targeted at the acquisition of the relevant compe-

tency. Learning mini-games could be performed with an instrument (voice/hand or guitar), with a system aid (e.g.acoustic and visual metronome); instead, relaxing mini-games represent *de facto* the last experience of each sub-block. These latter have a dual aim: (1) lowering the cognitive load preventing its overload, (2) entertaining learners with riddles and quizzes. Generally, mini-games related to an optional sub-block have a higher level of difficulty compared to those in the neighbouring mandatory sub-block. An example of a competency practice space is shown in Figure 5.

More details about learning and relaxing mini-games, and also as concerning their gamification aspects, can be found in (Caruso et al., 2019).

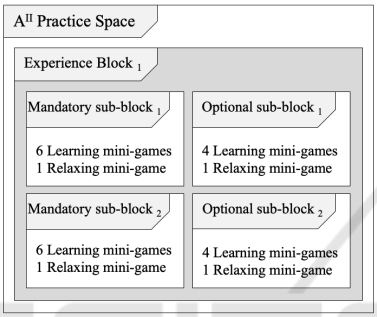


Figure 5: A^{II} Practice Space made by a single experience block.

4.3 Defining the Psycho-pedagogical Plan and the System Requirements

The psycho-pedagogical plan is strictly related to the performance obtained by learners (from now denoted with P) and concepts of musical achievement and aptitude.

Each sub-block can be passed with a certain grade of performance (i.e., Low, Medium, and High). Until performance remains below a given threshold (P=L) the sub-block has to be repeated, while the performance of a medium grade (P=M) unlock the following mandatory block; high grade of performance also unblocks optional sub-block. An experience block can be passed if the learners passed all its mandatory sub-blocks with at least a medium grade of performance.

According to these premises, each competency is achieved by traversing a path in its practice space. This learning path is not predefined for each learner and mirrors his/her musical achievement and aptitude; e.g., the number of optional sub-blocks disclosed and passed could be a metric for learner's level of musical aptitude.

Figure 6 shows all possible paths through sub-blocks belonging to the single experience block of competency A^{II}; being a simplification of Figure 5, lighter squares on the left represent mandatory sub-blocks, while darker squares on the right are optional sub-blocks.

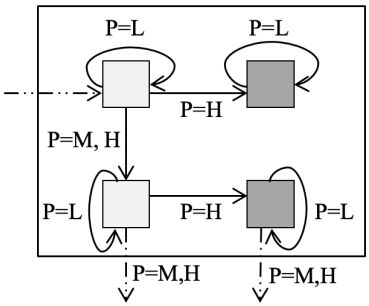


Figure 6: A^{II} - All possible paths inside the Practice Space, according to the grade of performance obtained in each sub-block.

With regard to system requirements, the outcomes of previous steps lead to their specification, which mirrors:

- The characteristics of learners, such as their needs, aptitudes, preferences and knowledge;
- The psycho-pedagogical assessment strategy and plan which have been defined according to the CrazySquare procedure;
- The specified context of use.

Both functional and non-functional requirements have been defined and the current prototyping solution fulfils most of them.

Main functional requirements are:

1. The System shall allow a non-registered user to create a new account; otherwise, to login in his/her account;
2. The System shall provide to each user a gamified learning experience appropriate to his/her learning path;
3. The System shall take as input sounds made by the users and recognise musical notes played by a guitar.
4. The System shall register all performances obtained by users playing with.

Main non-functional requirements are related to the characteristics of learners; these are the following:

1. The System shall be a software application running on android mobile devices (i.e.tablet and smartphone), with respect to users' preferences and aptitudes;

2. The System shall have a security control to let only Parents perform the registration in the name of their child/children, under regulations and guidelines in force, e.g. (EU-GDPR – Art. 8, 2016);
3. The System shall provide a UX/UI appropriate and adherent to main guidelines and design patterns in force, e.g. (Nielsen, 2019);

4.4 Prototyping Solution

The current prototyping solution of CrazySquare is a smartphone application designed to run only on Android devices. The application has been designed following the psycho-pedagogical strategies and plan, and it tries to meet the system requirements that have been defined.

To date, if a learner wants to start a learning experience via CrazySquare ICT-tool he/she must have a personal account; the system provides a way to create it by a two-step procedure: the first dedicated to the user, the second to his/her parents to get their explicit consent. Once the learners have their account, they could start their personal gamified learning experience articulated as a path through different mini-games in a way defined in the previous subsections. The GUI of the application has been designed in according with needs, aptitudes and preferences of learners who CrazySquare addresses, compliant with the main guidelines and suggestions in the field of pre-adolescents' UX/UI design (Nielsen, 2019). Some screenshots of the current prototype of CrazySquare are shown in Figure 7.

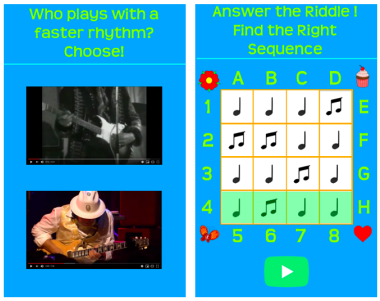


Figure 7: Some screens of the current prototype of CrazySquare: two examples of mini-games.

From a technical point of view, we can also say that the architecture of the application is built following the three-tier pattern described in (Sommerville, 2016). As shown in Figure 8, the presentation and logic tiers are deployed on the client-side, while the data tier on the server-side.

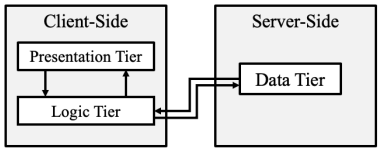


Figure 8: CrazySquare prototyping solution - System architecture.

Moreover, the application has been implemented using Android Studio and exploits several libraries, such as Tarsos-DSP and Android MIDI Library used, respectively, for pitch detection and generating MIDI files. More details about the overall aspects of the current prototyping solution can be found in (Caruso et al., 2019).

4.5 Evaluating the Psycho-pedagogical and System Solution

To design CrazySquare, we collaborated with three domain experts with background in music psycho-pedagogy and two domain experts with background in HCI and computer science. All domain-experts expressed positive impression and validated the efficacy of the psycho-pedagogy approach and the usability of the system, after the 2 steps of 2 cycles of iteration.

Consequently, in the next future, the evaluation of the current prototype with end users has been planned. To this end, a between-groups design is proposed with the following procedure. (i) The students, selected from the first year of Middle Schools, will be divided into two groups, matched for age and sex. (ii) At the start of musical teaching, both groups will be performing two tests appropriate for their age, i.e. Musical Aptitude Profile (MAP, (Gordon, 2001) that provides a *base-line* of musical aptitude and Intermediate Measures of Music Audiation (IMMA, (Gordon, 1986) that provides a *base-line* of musical achievement. (iii) One group will receive musical teaching using CrazySquare's psycho-pedagogical stimulation via paper and pencil (six months); while the other group will receive it using CrazySquare's psycho-pedagogical stimulation via ICT tool (six months). (iv) After these months, both groups will be performing again the MAP and IMMA. (v) The statistical analysis to evaluate the differences between groups on performance, musical aptitude and musical achievement levels, will be carried out. Thus, it will be verified whether the performance of students (including musical aptitude and musical achievement) who use CrazySquare ICT-tool is better than those who use the paper-and-pencil version of CrazySquare.

5 CONCLUSION AND FUTURE WORKS

In this paper, we introduced and discussed the current status of the CrazySquare project. It is a research and development project aiming at realizing an ICT support system for improving playing the guitar within Italian Middle Schools. CrazySquare is designed to the guitar instrument since it is one of the most played in the context of Middle Schools. The strength of the CrazySquare project, unlike the currently available ICT-tools for music education, is that it aims to guarantee the acquisition of the learning objectives that students should learn at the end of Middle School, as planned by the decree (Decree law no. 201, 1999). This can be carried out through a "*construction process"* since CrazySquare is based on two cornerstones: (1) the TEL-oriented UCD approach, (2) the TPACK framework. The former guarantees the compliancy of CrazySquare as an ICT-learning tool with a well-defined pedagogical theory (Gordon's MLT); the latter provides a model of technology-based instruction, integrating pedagogical and technological aspects to ensure the effective use of technology in teaching activities. In this way, CrazySquare could overcome the issues of the decree (Decree law no. 201, 1999) related to the lack of pedagogical and technological guidelines to achieve the learning objectives. Thus, it could be integrated into classroom practices as a support during the musical teaching activities and at home, as a support of homework activities. Overall, this paper provides a contribution to design issues related to the music teaching field, and especially in the technology-enhanced learning field. In each step of the CrazySquare's design, we have dealt with domain experts both in the field of psycho-pedagogy and HCI and computer science. All domain experts expressed a positive opinion and validated the efficacy of the psycho-pedagogy approach and the usability of the system. In the next future, the evaluation of the current prototype with end-users has been planned, as detailed in Subsection 4.5.

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