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Digital Music Learning Resources

From Research to Educational Practice

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Preface

Computer-supported music education refers to pedagogical practices that exploit the potential of digital technologies for music learning. Two factors are key to the development and spread of computer-supported music education. The first one is teacher preparation, which is a necessary prerequisite in order to deal with content transformation connected to the use of technologies; the second is the awareness and availability of devices, methods, and materials to support pedagogical activities.

The term “Digital Music Learning Resources” used in the title of this book refers to the wide and multi-faceted set of educational technologies that can be employed in all aspects of music learning. The integration of technology in music learning has long been recognized to have the potential for a profound impact on educational practices and learning outcomes.

Digital music learning resources can have an important role in motivating the interest of the students, helping their problem-solving abilities, and fostering multiple intelligence activities. They can foster hands-on, collaborative learning activities shared by students and teachers (e.g., creating a music production studio in the classroom), and they can allow for personalized instruction. The Covid-19 pandemic has further reinforced the awareness by teachers—and by society at large—of the importance of information and communication technologies for education, especially in distance-learning settings.

Over the years, research in educational technologies has produced a massive amount of approaches, publications, and applications aimed at enhancing learning in all aspects of music education, ranging from performance to theoretical subjects, up to creative activities. However, the distance separating research and educational practice, academics, and teachers is still wide. Possible causes include the gap between the oversimplified settings used in research for testing application prototypes and the actual context, problems, and constraints encountered in the classroom; the lack of common knowledge, especially in the technological domain; and the lack of a common language to facilitate the transfer of knowledge and productive dialogue between researchers and teachers. On the one hand, when a teacher approaches the world of digital materials for music education, s/he is overwhelmed by the number of available platforms and software, without having the possibility to evaluate what solution better fits her/his needs. On the other hand, these resources are difficult to access especially by teachers who are not versed in technology and need supporting tools to understand, catalog, and evaluate the available applications and solutions.

Starting from these premises, the present book aims at contributing to narrowing the distance between research and educational practice, by proposing (i) a comprehensive survey of the state-of-the-art of research in digital learning resources for music, and (ii) a conceptual framework within which the surveyed approaches, publications, and applications can be categorized. Specifically, a Taxonomy of Digital Music Learning Resources (TDMLR) is proposed, which is organized in various dimensions belonging to different domains (musical, technological, and pedagogical), along which the literature on technology-mediated music learning can be organized using a set of tags that are meaningful for both the researcher and the teacher.

In this publication we present TDMLR as a purely theoretical construct, focusing mainly on the basis for its development. At this stage, we put off its deployment and validation for further work. Actually, this would imply the definition of methods to obtain feedback from researchers, music teachers, and practitioners, and many other considerations about the gap between research and musical practice and its consequences that would go well beyond the scope of this book. However, we anticipate some of these issues in Chaps. 5 and 6. The taxonomy is built taking into account the technology integration process that characterizes contemporary music education. One particularly relevant theoretical reference is TPACK (Technological, Pedagogical, and Content Knowledge), which claims that the successful application of technology in educational practices can only stem from the integration of three different forms of knowledge: technological, pedagogical, and domain (musical, in this case).

The book begins (Chap. 1) with a brief historical excursus that starts from programmed instruction in the early 1950s and, through successive waves of information and communication technologies, arrives at contemporary educational platforms, digital games, and virtual environments for collaborative music creation. These developments are then re-examined through the lens of the main learning theories, which are introduced in Chap. 2. Rather than dwelling on the theoretical aspects, the chapter analyzes in detail the relationships between conceptual assumptions and the design principles of music educational applications. As an example, *Behaviorism* can be straightforwardly associated with linear and branching programs that govern the functioning of PLATO, one of the first educational programs born in 1960. However, very soon PLATO began to evolve toward multimedia, embedding more and more images, new touch screens, and also sounds. Thus the limits of programmed instruction and behaviorism began to be overtaken by the power of representations, which meet the idea of *Cognitivism.*

As a further example, Papert's *MicroWorlds* signaled a new way of using computers for education: in the wake of the theories of constructivism that emphasize that learners build their own knowledge based on the experiences they find in their environment, computers began to be considered as generous providers of such experiences in many ways.

As already outlined before, this very rich technological and pedagogical background is interpreted according to the TPACK framework, which is analyzed in Chap. 3 together with the SAMR (Substitution Augmentation Modification Redefinition) model. Both these models envision a change in the content as a consequence of technological integration. The content—in this case musical knowledge—is defined in the second part of the chapter, where the three artistic processes through which artists communicate with their audience are defined through nine standards. With this last definition the three domains of the TDMLR are established, and the taxonomy is thoroughly described in Chap. 4: a set of dimensions is proposed, which serve as the second level of classification along the three primary domains. A third level is formed by a number of nodes associated with each dimension, which can be used as tags for a specific contribution or application.

The following Chap. 5 outlines some practical functions and uses of the TDMLR. An extensive database of publications on digital materials aimed at music education is presented, along with a publicly available web platform that allows users to explore and navigate the publication database through the dimensions and nodes of the TDMLR. The advantages of a possible future role of TDMLR as a publicly negotiated taxonomy are outlined, and its contribution to item findability, content management, and knowledge management are discussed both for researchers and educators. Chapter 6 closes the book with some considerations about the relationships between research and educational practice, particularly about the main causes hindering a productive dialogue between teachers and researchers. Some proposals are formulated aimed at making such dialogue more effective and fruitful, including the role of the TDMLR in providing more accessible content for music teachers. The effort of the TDMLR could be further extended to meet the philosophy of Open Educational Resources (OER) in support of new pedagogical approaches and policies of open data to help the advances of research in the field of computer-supported music education.

Please note that the contents of this book are anglocentric in nature. This is due to a general lack of references to culturally diverse theories and musical practices in international scientific literature. We believe it is important to recognize and acknowledge this limitation in order to have a more inclusive understanding of music education in its various forms and styles.

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Contents

Acronyms

AI	Artificial Intelligence
CAI	Computer-assisted Instruction
DAW	Digital Audio Workstation
DSP	Digital Sound Processing
GTTM	Generative Theory for Tonal Music
GUIDO	Grade Units for Interactive DictatiOn
ICT	Information and Communication Technologies
IEEE	Institute of Electrical and Electronics Engineers
ITS	Intelligent Tutoring System
MEI	Music Encoding Initiative
MIDI	Musical Instruments Digital Interface
MIT	Massachusetts Institute of Technology
MOOC	Massive Open Online Courses
OER	Open Educational Resources
PI	Programmed Instruction
PLATO	Programmed Logic for Automatic Teaching Operations
SAMR	Substitution Augmentation Modification Redefinition
TDMLR	Taxonomy of Digital Music Learning Resources
TPACK	Technological Pedagogical And Content Knowledge
USA	United States of America
WWW	World Wide Web
XML	EXtensible Markup Language
ZPD	Zone of Proximal Development

Chapter 1
A Timeline of Music Education Technologies

Abstract This chapter analyzes the birth and evolution of educational technologies for music learning, from the origins of computer-assisted instruction (CAI) in the late 1950s to the present times. While following the main advances in educational technology in general, the main focus is on the history of the various approaches to music education: from the first computerized system for the assessment of sung melodies in 1967 to contemporary websites for music creation, collaborative composition, and experience sharing. The transformation goes from early platforms inspired by programmed instruction, through intelligent tutoring systems, to learning analytic technologies for providing adaptive learning environments. At the same time, the growth of computational power allows for human-computer interaction styles other than mouse and keyboard, calling into play virtual and augmented reality, motion sensors, and tangible interfaces.

1.1 Origins of Computer-Assisted Instruction

The evolution of educational technologies for music learning is intertwined with the broader field of educational technologies stemming from the interaction between theories and beliefs about human learning and technological developments (Gagne, 1987; Price, 1989; Spector, 2015). The origins of computer-assisted instruction (hereinafter CAI), in particular, can be traced back to the advent of the use of computers for educational purposes in the early 1960s.

1.1.1 Programmed Instruction and the Control of Learning

In an influential article, Skinner (1958) thoroughly describes the working of his teaching machine, a mechanical device composed of a wooden box and paper disks, each containing 30 radial frames of information (see Fig. 1.1). This method of content

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Fig. 1.1 Skinner's teaching machine: paper disks containing the educational programs were inserted into the wooden box and the text appeared in the window on the cover. Lifting a lever in the front allowed the student to check the response and advance to the next frame. Picture from Wikimedia Commons (https://upload.wikimedia.org/wikipedia/commons/2/2d/Skinner_teaching_machine_08.jpg)

presentation is the core of programmed instruction: knowledge is organized into a sequence of frames, small units of information concatenated in progressive order. Students insert the disks inside the box and work individually at their own pace. After responding to each frame, students can check their responses and receive additional information on the subject. If a response is wrong further attempts are allowed until it becomes correct.

This organization into frames shapes learning as incremental progress with immediate feedback that helps students realize autonomously the degree of knowledge achieved. This necessity responds to precise social and political objectives. As reported by Wiburg (1995), after the end of World War II, the USA was in the middle of the Cold War and under the urge of strong competition with Russia for the conquest of space. These circumstances increased the need for fast and efficient training of military and scientific personnel and made the promises of programmed instruction appear as the best solution for the system of public instruction. Skinner's teaching machines could serve a higher number of students at a lower cost, provide individualized learning, and deliver an immediate evaluation of the student's performance. For these reasons, programmed instruction and teaching machines became very popular in colleges, schools, and military services throughout the 1960s.

On a more theoretical level, Skinner's programmed instruction and teaching machines were profoundly influenced by *Connectionism* and *Behaviorism*, according to which learning is produced by a change in behavior determined by positive reinforcement and repeated trials. These learning theories are discussed in Chap. 2.

1.1.2 Early CAI and the PLATO System

The first attempts to use computers to deliver education date back to the late 1950s, when they were used to train computer industry employees. With the goal of reducing the difficulties in writing educational programs, in 1960 IBM released *Coursewriter II*, the first authoring language for course preparation, thus opening the way to the development of CAI. The first programs to appear and be tested in an elementary school in 1965 were produced by Stanford University and were used to teach mathematics and logic through a typewriter system connected via a telephone line. Programs for teaching mathematics and English language in elementary schools remained in use in subsequent years, while in 1967 the first university-level program for teaching Russian was created at Stanford University (Suppes and Macken, 1978).

All these programs were based on the principles of programmed instruction, which was straightforwardly transferred from Skinner's teaching machines to computers. As depicted in Fig. 1.2, programmed instruction may be organized in linear programs or branching programs, depending on how mistakes are treated. Linear programs proceed from frame to frame independent of the answer's accuracy; branching programs organize the sequence of frames according to the learner's answers, allowing them to skip or repeat frames depending on the user's ability (Kay et al., 1968).

Programmed instruction met severe criticism from educators and students, who found it boring and effective only in teaching nothing more than mere facts (Price, 1989). Moreover, it soon became clear that writing efficient educational programs was all but simple, as it not only entailed a very high level of knowledge of the subject but also required the ability in arranging the order and coherence between frames and in determining response adequacy (Markle, 1964). High costs of computer systems

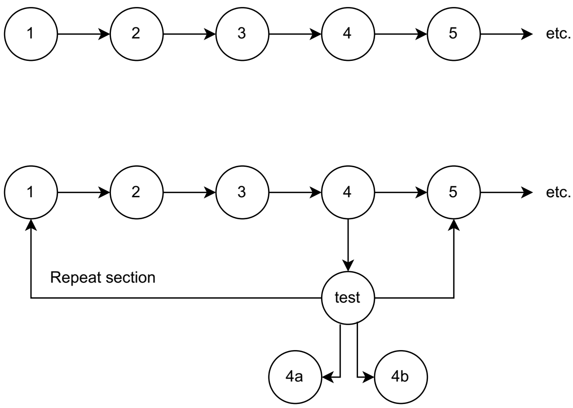

Fig. 1.2 A linear (above) versus a branching programming organization (below) as planned by (Crowder, 1963). Image adapted from Clark (2004)

Fig. 1.3 Interactivity with the first touchscreen implemented for the PLATO IV system. Image with permission from Paul J. Tenczar, University of Illinois

at the time, together with the issues listed above, prevented the wide adoption of CAI, at least until the beginning of the 1980s.

In the 1970s, the University of Illinois received a government grant for the development of the *Programmed Logic for Automatic Teaching Operations* (PLATO hereinafter) system (Smith and Sherwood, 1976), the first systematic project aimed at CAI. Development had already started in the 1960s and in subsequent years went through several phases, which saw continuous progress toward functionality and multimedia communication.

PLATO I (1960) only included a screen for data visualization and a keyboard for menu navigation. PLATO II (1961) added multi-user capabilities, two students at a time, while PLATO III (1963–1969) enriched the system with Tutor, an authoring program allowing customization of the educational programs. Moreover, PLATO III could run on 20 computers at the same time, even through a remote connection. PLATO IV (1972) was endowed with a plasma screen for improved color graphics, a touchscreen system for delivering responses (see Fig. 1.3), a random-access audio device, a human voice synthesizer, and a four-voice music synthesizer. The system could provide interactive and self-paced instruction to a large number of students with a number of terminals that in 1976 totaled up to 950 among universities, colleges, military and commercial organizations (Smith and Sherwood, 1976).

According to Hofstetter (1981), by 1981 the PLATO system could count applications for higher education ranging from sciences to graphic design, music theory, and counseling, additional ones at the pre-college and commercial levels, and even multiplayer online games (Woolley, 1994). Thanks to its multimedia equipment, the system offered not only drill-and-practice activities but also tutorials, simulations, gaming, and testing activities. The main recognized benefits of the system included the ability to deliver high-quality individualized instruction with a reduction in learning times, a deeper understanding of complex phenomena with immediate feedback, and increased motivation toward learning.

1.2 The Birth of Computer-Assisted Music Education

Programmed instruction was soon applied to the development of simple ear training exercises aimed to support early music education. Examples include programs for interval recognition (Spohn, 1959) and melodic dictation (Carlsen, 1962). These systems employed magnetic tapes, programming books, and worksheets to manually annotate the answers. Even Skinner (1968), in a review of his teaching machines, mentions a system for training rhythmic abilities by tapping a rhythmic pattern in sync or in response to clicks produced by a suitable device. Another machine for training musicianship was composed of a small keyboard and a dispenser. The machine played single notes, intervals, or melodies. The student answered by repeating the patterns on the keyboard where only the correct keys were left active. The reward for the right answers (candies or coins) was delivered to the student by the dispenser (Skinner, 1968, pp. 69–71).

1.2.1 The First Computer Programs

The first computerized program for music education was produced in 1967 at Stanford University by W.E. Kuhn and R.L. Allvin. To ensure a more direct form of assessment of students' responses, the system was endowed with a pitch extraction algorithm to judge the accuracy of sung melodies (Kuhn and Allvin, 1967). Table 1.1 reproduces a print-out of the result from Exercise 3, where the student has to sing a melodic sequence proposed by the computer: in this example, the student's response is evaluated negatively by the system, which does not allow her to proceed to the next exercise, but rather suggests the repetition of the same one. This is an example of a branching program as depicted in Fig. 1.2.

The possibilities offered by the PLATO project were further exploited to develop programs for music education. From 1969 to 1973, researchers such as D. Peters and R.W. Placek endowed the system with music education programs for pitch and rhythm detection (Peters, 1974; Placek, 1974). In the late 1970s, J.O. Froseth and W.H. Sanders added slides and images to help students identify typical posture or hand placement errors in instrumental playing, additionally providing an assessment study on learners' reactions to the system (Sanders, 1980). In 1981 N.T. Watanabe introduced a system that employed random-access audio to teach instrumental timbre identification by sound, extending thus the aims of computer-supported music education in the PLATO system (Watanabe, 1981).

Table 1.1 Print-out example of a singing exercise of the computerized system by Kuhn and Allvin (1967). Table adapted from Kuhn and Allvin (1967)

Exercise ID	Exercise 3—Set 80				
Starting instructions	Ready? (Subject presses “ready” key)				
	Sing (Subject sings exercise)				
Note sequence	**A**	**B**	**A**	**C**	**A**
Evaluation from the system	**OK**	**OK**	**C**	**A**	
System feedback	Too few notes. Repeat Exercise				

1.2.2 The GUIDO System

Starting from 1974 the *Grade Units for Interactive DictatiOn* (GUIDO hereinafter) system, after Guido D’Arezzo was developed at the University of Delaware. It consisted of a series of programs for ear training and aural skills development. The system compared students’ answers to a set of pre-stored responses. Arenson and Hofstetter (1983) provide a thorough description of the system. The heart of GUIDO was its learning unit design, which was based on a master table where all the parameters of a unit were organized to provide the best sequencing instructions. As an example, a learning unit for melodic dictation included the mode of dictation (harmonic, melodic, ascending, and descending), the length of the trials, the number of consecutive trials, the time allowed for response, and so on. However, these parameters were not fixed but could be modified by the instructor by typing different values inside the table.

The GUIDO learning station was composed of a micro PLATO display, a sound synthesizer, a set of earphones, and a floppy disk drive. The interaction was made more immediate by the touch capabilities of the PLATO screen. The education program of GUIDO consisted of ear training and music theory lessons. Content and response modalities for the ear training program are displayed in Table 1.2, while categories and lessons of the music theory program are displayed in Table 1.3. As an example, for the lessons on Intervals, the user interface presented a simple layout with boxes containing intervals to be selected, different options for playing them back, and a stylized keyboard where either the bottom or the top interval notes could be displayed depending on the chosen playback modality.

Table 1.2 The five lessons of the ear training program in the GUIDO system, taken from Arenson and Hofstetter (1983)

Ear training	
Lessons	Interaction
1. Intervals	GUIDO plays an interval The student touches the box with its name
2. Melodies	GUIDO plays a melody The student touches the boxes with correct pitches
3. Chord qualities	GUIDO plays a chord The student touches the control box with the response
4. Harmonies	GUIDO plays a four-part chorale The student touches Roman numerals and soprano and bass notes
5. Rhythms	GUIDO plays a rhythm The student touches the boxes with the correspondent note values

1.3 Beyond Programmed Instruction (The 1980s and 1990s)

The introduction of microcomputers into schools dates back to the early 1980s. Apple II[1] was the leader in the educational sector, where the increased computational power led to a demand for new and more complex software products (Price, 1989). At the same time, the instructional effectiveness of CAI programs and the soundness of their design were assessed in several studies (Hofstetter, 1978; Edwards et al., 1975).

Some of these studies contributed to fueling criticism about programmed instruction. As an example, Gross (1984) reported the result of research about learning music with CAI, which hinted at its limited efficiency when dealing with larger-scale topics, i.e. more complex problems than identifying intervals and chords. Thus, the quest for more complex programs was on the way. At the same time, music technology advanced tremendously during these years. Digital synthesizers, samplers, sequencers and drum machines, MIDI-enabled interfaces, digital audio editors, and workstations, all started to appear on the market during the 1980s. MIDI in particular, first proposed by Smith and Wood (1981), was a truly transformative technology: the availability of MIDI editors made it possible for a user with no knowledge of music notation to produce rich arrangements and to compose music utilizing intuitive techniques such as pitch transposition, non-linear editing (e.g., cut-and-paste), and so on. Since the late 1980s, applications originally born as MIDI editors (such as *Cubase*[2] and many more) soon integrated audio editing capabilities, thus converging towards current digital audio workstations. Although developments in this field were mainly driven by the needs of the music industry, the impact on music education practices was considerable (Webster and Hickey, 2006).

[1] https://americanhistory.si.edu/collections/search/object/nmah_334638.

[2] https://new.steinberg.net/cubase/.

Table 1.3 The seven categories and thirteen lessons of the music theory training program in the GUIDO system, taken from Arenson and Hofstetter (1983). Interaction is reported only for discussed cases in the original paper

Music theory (written)		
Categories	Lessons	Interaction
1. Basic elements of pitch	a. Pitch identification	
	b. Octave designation identification	Touch the appropriate boxes to identify the note and its correct octave displayed on a grand staff
	c. Half steps and whole steps	
2. Rhythm	d. Beat units and divisions	Identify beat when a division/subdivision is given
	e. Meter and time signatures	
3. Scales and keys	f. Scale types	Touch the boxes with the appropriate chromatic signs for the notes belonging to a given scale
	g. Key signatures	
4. Intervals		Touch the quality and the number of the interval displayed on a staff
5. Chords and harmony	h. Diatonic chords	Identify and construct various types of chords, identify scale degrees and inversions
	i. Basic part writing	
	l. Bass figurization	
6. Transposition		Transpose melodic figures in various ways: by interval, by key, or for a transposing instrument
7. Partials		Given the fundamental, construct the first seven or fifteen overtones; or assign a partial to all possible overtone series

1.3.1 *The Rising of Artificial Intelligence*

Starting from the 1970s, approaches based on *Artificial Intelligence* (AI hereinafter) were proposed to add smart decision-making capabilities and more flexible features to the learning environment (Carbonell, 1970). According to Holland (2000), the history of AI in education can be subdivided into a "classical" and a "modern" phase. The applications of the classical phase (from 1970 to 1987) are based on the Intelligent Tutoring System (ITS) architecture, which is composed of four elements: the domain model, the student model, the tutoring model, and the user interface, as depicted in Fig. 1.4. The domain model represents expert knowledge and contains information about the domain to be taught. The student model should provide information about

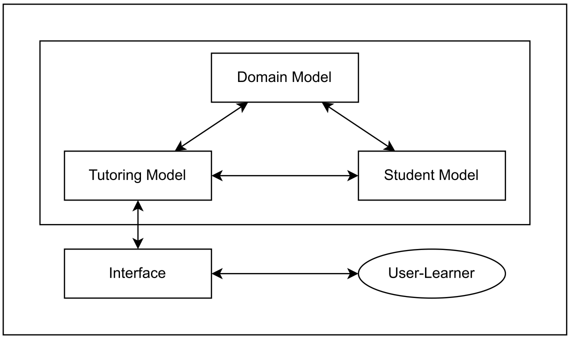

Fig. 1.4 The architecture of an intelligent tutoring system with its four components: the domain model, the student model, the tutoring model, and the user interface. Image adapted from Nkambou et al. (2010)

the student's level and progress. The tutoring model is fed by both the domain and the student model and is responsible for tutoring plans and content delivery. All this information flows through the interface which gives access to domain knowledge (Nkambou et al., 2010). Examples of ITS are reported in Sect. 1.3.2.

A highly influential idea, coeval to the ITS-based architecture of the "classical" phase, is the Logo approach. S. Papert and his research team at MIT (Massachusetts Institute of Technology) produced in 1967 *Logo*, a language for programming *MicroWorlds*, multimedia learning environments aimed at involving students in more engaging learning activities and element manipulation.[3] As noted by Holland (2000), although Microworlds associated with the Logo approach do not involve any AI at the point of delivery, their design is strongly influenced by AI methodologies and tools. *MicroWorlds* and *Logo* can be used for various purposes, including the study of mathematics (Hoyles and Noss, 1992; Edwards, 1995), computer programming (McNerney, 2004), or technical subjects (Mayer et al., 2003), but also to the creation of music learning environments such as *MusicLogo* (Bamberger, 1979) and *LOCO* (Desain and Honing, 1988).

Bamberger (1979) in particular developed *MusicLogo*, which comprised a series of activities focused on procedural thinking in music. In the *Tuneblocks* games, simple melodies are built by combining different elements, or the same elements may be re-assembled to compose a different melody. Simple procedures are employed to edit notes, durations, and rests. As an example, the instruction

```
PLAY [0 0 7 7 9 9 7] [2 2 2 2 2 2 4]
```

plays the first phrase of "Twinkle twinkle little star". Starting from the observation of how children perceive a melody, the author first proposed a series of activities that outline the structural properties of the melody and then introduced the use of the computer. The *Improptu* music program allows the organization of the *Tuneblocks* into a graphical environment, realizing the visualization of multiple representations of a melody, as depicted in Fig. 1.5.

[3] https://el.media.mit.edu/logo-foundation/index.html.

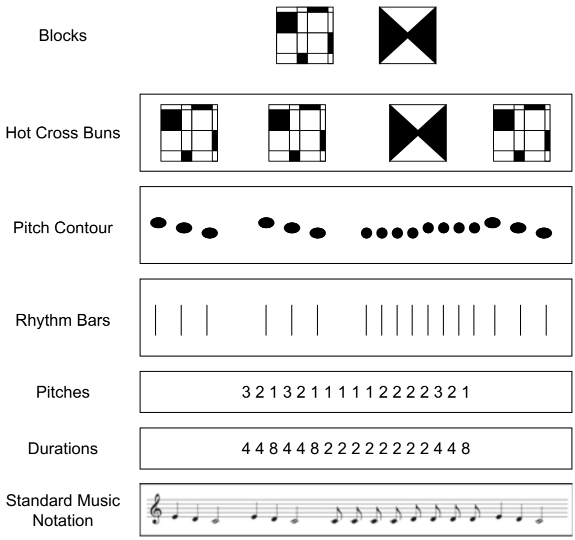

Fig. 1.5 Multiple representations in the *Improptu* environment of the melody "Hot cross buns". Image adapted from Bamberger (1999)

The heir to the experience of Papert's *Microworlds* is *Scratch*, a visual programming language designed at MIT Media Lab in 2007.[4] Combining different blocks of code *Scratch* allows for the realization of animations, games, digital stories, and simulations. It has also been used for designing music composition experiences, such as those described by Brown and Ruthmann (2020), where computational thinking concepts are introduced such as looping, initialization, use of variables, dynamic changes, modularization, and event processing (Ruthmann et al., 2010).

Finally, the "modern" phase (from 1987 onward) identified by Holland (2000) extends AI features beyond the simple assessment of already consolidated knowledge. Approaches considered include frameworks for cognitive support that employ models of creativity, highly interactive interfaces that employ AI theories, AI-based music tools, and systems to support negotiation and reflection. The author reports a wide variety of examples illustrating these approaches.

1.3.2 Applications for Different Musical Activities

In a review of the use of computers in music education Brandão et al. (1999) offer a wider perspective of music education applications by time. Four main groups of educational applications are identified by the authors, based on their respective domains:

1. Fundamentals of Music;
2. Music Performance;

[4] https://scratch.mit.edu/.

3. Music Analysis;
4. Music Composition.

Within the first group, ear training and music theory programs proved to be reliable and efficient for teaching basic elements of western music (pitches, intervals, melody, chords, rhythms, etc.) (Kulik et al., 1983). Thus programs such as *MacGAMUT*[5] and *Practica Musica*[6] survive to present days and, although enriched by the use of MIDI keyboards and multimedia content, essentially do not differ much from the structure of programmed instruction. On the other hand, the remaining groups of applications diverge substantially from the framework of programmed instruction, mainly for two reasons. Firstly, they deal with more complex problems than the detection of intervals and chords, which are not fully representative of 20th century and non-western music. Secondly, they are inspired by learning theories that progressively abandon *Connectionism* and programmed instruction to explore the cognitive aspects of learning such as experience and discovery (Brandão et al., 1999).

Music performance is addressed in the second group of applications, which most typically rely on piano-roll visualizations to render feedback on students' performance. *Piano Tutor* is perhaps the most innovative system of this kind. This is an ITS, which embeds a score-following system, an acoustic or digital piano with MIDI, a video-disc player, color graphic displays, and synthesized sound. The tutoring model relies on an expert system that contains encoded information about the knowledge required to teach piano. The student receives a score with a new piece. The system can detect mistakes in performance and give information about how to correct them (Dannenberg et al., 1990).

In the group of music analysis, applications at the time focused mainly on event counting (pitch recurrence, note values, and intervals), thus providing useful sets of quantitive data related to different musical styles. However, different approaches to music analysis were also proposed following influential theories such as H. Schenker's transformations implemented by Smoliar (1979) and *Generative Theory for Tonal Music* (GTTM) implemented by Robbie and Smaill (1995).

The last group of applications deals with the complex domain of music composition, which is understood in a wide sense by Brandão et al. (1999), including musical games and learning of specific music styles. Typical approaches were based on either specialized ITS or interactive games. Examples of ITS are *Lasso*, devoted to learning 16th Century two-voice counterpoint (Newcomb, 1985), and *Vivace* for learning 18th Century four-voices chorales. *Vivace* took a choral melody as input and returned the remaining three parts (bass, tenor, and alto) relying on a set of rules derived from manuals and textbooks (Thomas, 1985). An example of an interactive music composition game is the already cited *Music Logo*, where children combining *tuneblocks* could compose a melody and discover the musical rules lying behind the building of a sensible sequence (Bamberger, 1979).

[5] https://www.macgamut.com/.

[6] https://www.ars-nova.com/practica6.html.

1.4 Going Online (The 2000s)

The possibility of producing music without either knowing music notation or being able to play a musical instrument discloses the realm of musical creativity to new categories of users who could not access it before. The availability of more and more efficient and affordable professional digital audio workstations made home production a reality that revolutionized the music market. All these significant advances in music technology had important consequences for the music industry, music culture, and, of course, music education.

1.4.1 Participation and Collaboration on the Web

In the early 2000s, the World Wide Web began to evolve from a "read-only" (Web 1.0) to a "read-write" modality (Web 2.0) (Salavuo, 2008). This process—popularized by O'Reilly (2005)—signed the transition from static to dynamic, user-generated content, providing users with the possibility to upload their own materials on the web and interact in real time with other users.

The advent of Web 2.0 brought access to large online archives and audio sample repositories. *Choral Public Domain Library*,[7] *International Music Score Library Project (IMSLP) – Petrucci Music Library*,[8] and *Freesound*[9] stand as relevant examples. An impressive number of resources for music learning are available online, such as *musictheory.net*,[10] *SmartMusic*,[11] and *Soundfly*.[12]

In addition to being a source of information and a repository of learning resources, the World Wide Web also became a virtual place for music production and sharing. An early example of collaborative music making is provided by Seddon (2006), who describes a shared composition experience between pairs of 13/14-year-old students belonging to Norwegian and English schools. Collaboration was asynchronously established through e-mails with textual and music exchanges. Brown and Dillon (2007) employed *jam2jam*, a network improvisation system that connected several computers in an ensemble over the internet. Real-time improvisation showed great potential for the engagement of the students and the development of their listening abilities. In subsequent work, Dillon et al. (2009) presented software for generative music-making which displayed a virtual music ensemble allowing for direct manipulation of musical parameters and supporting a sense of relationship and identity through the common music experience. Following similar ideas Miletto et al. (2011) presented *CODES* (COoperative Music Prototype DESign), a web-based networked

[7] https://www.cpdl.org/.

[8] https://imslp.org/.

[9] https://freesound.org/.

[10] https://www.musictheory.net/.

[11] https://www.makemusic.com/for-education/.

[12] https://soundfly.com/.

music environment designed to support prototypical and cooperative ways of music creation by novices.

Ruismäki and Juvonen (2009) provided a comprehensive summary of the new horizons opened by Web 2.0: collaborative music making, music sharing, online music education, music games, and widespread informal music learning. These elements also characterize the many online music communities that proliferated, either through *ad-hoc* created platforms or by exploiting existing social platforms. Famous examples include *MySpace*,[13] *SoundCloud*,[14] *Facebook*,[15] or *MeetUp*[16] (Salavuo, 2008). These were born to offer virtual meeting points for artists to showcase their work and fans to share opinions and appreciation and supported such activities as uploading one's music for feedback, listening to contributed music and providing feedback, discussing and recommending music, and connecting with other musicians in joint projects. Collaborative music composition platforms, such as *Flat*[17] and *Noteflight*[18] offer not only the possibility of sharing the products of musical creation but also the opportunity of participating in the creation itself. A related phenomenon is represented by the growth of online communities of practice (Waldron, 2009; Wenger, 1998), which assemble groups of amateurs with shared interests in specific music genres.[19]

1.4.2 Technologies for Online Music Learning

According to Adesope and Rud (2018), the array of technologies available for the 21st Century educator is very rich. A non-exhaustive list includes wikis and social media platforms, digital games, MOOCs, extended realities, and learning analytics. These are briefly reviewed below, and their application in the field of music education is outlined.

- **Wikis and social media platforms** are very popular educational tools. Although their use in class activities may bring some concerns with respect to inappropriate communication, privacy, and children's security, social media can provide an important aid to teaching activities. Particularly, social media in music education can support online communities of practice where to exchange experiences among peers, learn through inquiry, and reflect on the learning experience (Albert, 2015).
- **Digital games** have attracted the attention of educators for their potential in involving students. Embedding games in educational practice can be time-consuming and

[13] https://myspace.com/.

[14] https://soundcloud.com/.

[15] https://www.facebook.com/.

[16] https://www.meetup.com/.

[17] https://flat.io/.

[18] https://www.noteflight.com/learn.

[19] An example of old-time American music styles is Blue Ridge: https://www.blueridgemusicnc.com/listen-and-learn/music-styles/old-time.

requires some effort and ability by the teachers for planning the proper pedagogical activities (Gros, 2007). Digital games turned out to be a good means for connecting formal and informal music learning (Cassidy and Paisley, 2013), delivering cognitive and educational benefits to the students (Baratè et al., 2013).

- **MOOCs** (Massive Online Open Courses) were designed with the aim of delivering instruction to a large number of students, employing at the same time a reduced number of teachers and technical staff. MOOCs are characterized by very short learning units based on video lectures, exercises, articles, software, links, and final assignments. They try also to bring students together and simulate a real class environment by creating student networks and building collaborations among participants. Data related to students' activities can be stored for further analysis aimed at improving learning and engagement. Examples of the use of MOOCs for music education are reported by Steels (2015).
- **Extended reality** technologies have become widely available in recent years, while the quest for more immediate and efficient human-computer interaction stimulated research on tangible interfaces, motion tracking, and multimodal interaction. The new frontiers of augmented and virtual reality promise a future where music-making can be ubiquitous and completely independent of physical instruments or devices (Serafin et al., 2017). Particularly large-scale interactive environments characterized by physical engagement and full-body interaction can be used for music education and rehabilitation of impaired people (Mandanici et al., 2018).
- **Learning analytics** refers to "[…] the development and application of data science methods to the distinct characteristics, needs, and concerns of educational contexts […]" (Wise, 2019). Learning platforms, MOOCs, and collaborative media produce massive amounts of data related to users' performances, preferences, and behavior. These data may be used to improve the quality of learning services and to build user profiles for delivering personalized educational programs to students (Becker et al., 2018). Useful information from data generated by students' activities through various techniques, including machine learning, can be used to make their experience richer and more personalized (Delgado et al., 2013). As an example, machine learning is used to support music performance software such as *SmartMusic*[20] or music composition platforms such as *Amper*[21] and *Magenta*.[22]

1.5 Summary

In this chapter, we presented a short overview of computer-assisted music education, from the very early experiments of programmed instruction designed according to the behaviorist model of B.F. Skinner to contemporary online learning environments. We first described the birth of computer programs for ear training and music theory

[20] https://www.makemusic.com/for-education/.

[21] https://www.ampermusic.com/.

[22] https://magenta.tensorflow.org/.

such as GUIDO, and then their evolution towards more complex tasks, such as music composition and performance. Contemporary technologies involve the affordances offered by the World Wide Web through which it is possible to practice collaborative music-making, music sharing, and online music education.

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Chapter 2
Learning Theories and Technology-Based Learning Approaches

Abstract This chapter introduces the most relevant learning theories and their implications for the design of music education applications. Understanding learning theories means analyzing in depth the processes that lead to obtaining information and deriving meaning from it. There are important relationships between the goals to be achieved and the application's instructional design, which depend also on the available technologies. All these interconnections are the core of the present chapter, which encompasses psychological research, learning theories, application design, and actual examples. The final section focuses on the changes that occurred between the actors of the learning process (students, teachers, and knowledge mediated by technological means) as a consequence of the advent of communication technologies. Formal and informal learning, online and blended learning form a composite ensemble of educational possibilities which teachers are called to confront.

2.1 Learning Theories

The birth of modern psychology in the last century paved the way for further developments in the understanding of the processes that drive learning. This led educational psychologists and philosophers to develop different theories of learning. According to O'Neill and Senyshyn (2011), a learning theory is not only a way to explain how people process information to gain new knowledge and skills, but rather a way to define the idea itself of what learning means in terms of expectation, thought, intelligence, perception, and experience. These elements are important for shaping the educational approach and, consequently, the instructional design of applications for technology-assisted education. For these reasons, the most influential learning theories as presented by Schunk (2019) will be shortly revised in the next sections, not so much to repeat concepts that are better addressed elsewhere, but rather to summarize them in relation to their implications for music teaching, and for re-examining through this lens the applications already discussed in Chap. 1.

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Table 2.1 Chart of the three reviewed learning theories, adapted from Schunk (2019)

Theory	Behaviorism	Social cognitivism	Constructivism
Summary	Learning as a reaction to environmental stimuli	Learning as processing information acquired in a social environment	Learning as the result of individuals' construct and sociocultural influence
Key contributions	Behaviorism (Watson, 1919); Operant Conditioning (Skinner, 1938)	Social Cognitive Theory (Bandura, 1986)	Theory of Cognitive Development (Piaget, 1952); Zone of Proximal Development, Activity Theory (Vygotsky, 1978)
Instructional implications	Programmed Instruction; Drill and Practice; Positive/Negative reinforcement	Enactive and Vicarious Learning Modeling; Self-Efficacy; Worked Examples; Tutoring and Mentoring	Discovery Learning; Inquiry Teaching; Peer-Assisted Learning; Reflective Teaching
Application examples	Kuhn and Allvin (1967); GUIDO (Hofstetter, 1975)	The Piano Tutor (Dannenberg et al., 1990); Digital Violin Tutor (Yin et al., 2005); VEMUS (Tambouratzis et al., 2008)	MicroWorlds (Papert, 1987); MusicLogo (Bamberger, 1979); Scratch (Brown and Ruthmann, 2020); jam2jam (Brown and Dillon, 2007); Dance eJay (Mellor, 2008); JamMo (Paananen and Myllykoski, 2009)

The theories of *Behaviorism*, *Cognitivism*, and *Constructivism* are the most relevant ones in the field of computer-mediated education since they have specific areas of reference in the history of CAI, and are reviewed in the next sections. As depicted in Table 2.1, each theory is described through its theoretical contributions, main instructional implications, and examples of music-oriented educational applications.

2.1.1 Behaviorism

E. Thorndyke is the father of *Connectionism*, a learning theory derived from the observation of animal behavior. Starting in the late 19th century, he developed the so-called S-R framework, which defines learning as a series of associations between stimuli (S) and responses (R). Animals learn how to obtain food by associating a particular movement (e.g. the pressing of a lever) to food release; humans essentially apply the same mechanism in a more refined way by creating various S-R associations, repeating them many times, and receiving an appropriate reward for their actions.

Thorndyke's work anticipated the ideas put forward by *Behaviorism*, aimed at developing a systematic approach to understanding the behavior of humans and other animals. J.B. Watson is generally considered to be the founder of modern behaviorism: he advocated a highly descriptive and objective approach to psychology, viewed as an experimental branch of natural sciences, in which only observable behaviors were considered to be proper material for psychologists to study whereas thoughts and feelings, being unreliable and not measurable, were not. Particularly, the classical (or respondent) conditioning theory proposed by Pavlov and Gantt (1929) had a major influence in the building of Watson's own theory (Watson, 1919). The implications of Watson's work were further elaborated by B.F. Skinner, who in 1938 published his theory of *operant conditioning* (Skinner, 1938). In this view, learners make associations between a given behavior and its consequences, favoring actions followed by pleasant effects compared to those followed by unpleasant ones. This mechanism leads to a reinforcement effect for the most repeated behaviors.

The principles of *operant conditioning* were rendered by Skinner through *programmed instruction* (Skinner, 1958), already discussed in Sect. 1.1.

Programmed instruction well represents the typical behaviorist concept of *drill and practice*, which relies on repetition for acquiring new skills and on the adoption of rewards for positive reinforcement. In Skinner's words, the main assumption of programmed instruction is not *…proving or disproving theories but […] discovering and controlling variables of which learning is a function* (Skinner, 1958, p. 2). The early applications for computer-assisted music education discussed in Sect. 1.2 (Kuhn and Allvin, 1967), including the GUIDO system (Hofstetter, 1975; Eddins, 1981), provide examples of programmed instruction in music education. However, by today's standards, they offer limited flexibility and customization to learners' individual needs (McDonald et al., 2005).

As discussed by O'Neill and Senyshyn (2011), *Behaviorism* shapes the idea of a musician who is a skilled performer, trained to receive direct instructions and to play music in the most accurate way. The search for objectivity underlying the behaviorist approach is realized in the definition of learning goals arranged in sequential order and of increasing difficulty. This is all but a trivial task, which requires a profound knowledge of the subject at hand. These activities are the basis of the work of Boyle (1974), who proposed guidelines, actions, and assessment methods for effective musical training. The quantitative assessment of musical abilities is another qualifying point of the behaviorist approach. In the field of music education, this is famously represented in the work of Gordon (1965), who proposed various sets of tests for measuring students' musical aptitude.

In summary, the behavioral view suggests that learning must be supported by rewards, that can bring positive reinforcement to the learner. This concept ties up behavioral psychology to the techniques employed in contemporary games or gamification approaches for education. Particularly points, badges, leaderboards, and time constraints are used to engage the players in the game, with the aim of observing, measuring, and stimulating learning (Linehan et al., 2015).

2.1.2 Cognitivism and Social Cognitive Theory

In the early 1960s, *Behaviorism* began to be challenged by many scholars and by different theories. One of the reasons for this criticism is that *Behaviorism* considers learning exclusively as a reaction to external environmental stimuli, completely disregarding the internal structure of the student's mind. For music in particular, a behaviorist approach makes learning a passive, mechanical, and rigid activity that leaves out all the vitality and richness of the musical experience. In contrast, *Cognitivism* claimed that a deeper understanding of internal processes is needed in order to understand the complexity of the learning experience (Rideout, 2002).

In a cognitivist view, learning is still dependent on external environmental stimuli but, differently from *Behaviorism*, the focus is on the mental processes necessary to receive, organize and store information. Particularly, information processing theories aim at understanding how people select and pay attention to environmental stimuli, transform and repeat information, link new information to what they already know, and organize information to make sense of it (Mayer, 1996).

One important theory of information processing is represented by the *Gestalt* laws, which describe how the brain organizes perceptual information according to similarity, proximity, continuity, common fate, and closure of elements (Wertheimer, 1938). Although originally conceived for visual stimuli, the "Gestalt" laws can be used to interpret auditory stimuli as well, offering meaningful insights about the mechanisms that govern musical listening (Plack and Moore, 2010). Other important theoretical tenets are those derived from N. Chomsky's studies about verbal syntactic structures (Chomsky, 1957). These formed the basis for the work of F. Lerdahl and R. Jackendoff, who considered a tonal piece as the superposition of various layers, each characterized by different rules (Lerdahl and Jackendoff, 1996).

One of the main challenges to *Behaviorism* came from the *social cognitive theory* (Bandura, 1986), which relies on the observation that people can learn actions, gestures, skills, and strategies by simply observing others in a social environment. Thus, learning may occur either by actively imitating models and experiencing the consequences of these actions (enactive learning) or by observing models in a real-life setting or through symbolic or portrayed representations (vicarious learning). Within this framework, important instructional implications may be outlined, such as *teacher/peer modeling* and *self-efficacy*. Teacher and peer models are a primary source of information as they can best guarantee students' self-efficacy, that is the learner's ability to evaluate how well a given task can be executed. For this kind of learning, the availability of *worked examples*, i.e., step-by-step demonstrations of how to accomplish a task, is crucial and is especially useful to reduce cognitive load and to ensure efficiency in delivering training materials (Kalyuga et al., 2000).

In this context, *multimedia learning* acquires the role of a powerful facilitator. According to Mayer (2002), content can be better delivered through multimedia (i.e. written text and images) than with text alone. The same concept may be extended to music learning, where the coupling between sound and graphical representation can provide interesting insights into music cognition (Bamberger, 1982; Davidson and Scripp, 1988). Graphic representation of sound events is also used for drawing listening maps that are an efficient tool for engaging children in the discrimination of aural elements (Gromko and Russell, 2002). Technology can help by combining different visualization systems for enhancing music appreciation and element detection as in the DML system by Yu et al. (2010), or by allowing the building of interactive listening maps, as with the Acousmographe,[1] a tool for the synchronization of non-written electroacoustic music with graphics and text.

Other important teaching implications of *Cognitivism* are *tutoring* and *mentoring* activities. Tutors serve as instructional models for trainees, while mentors extend advising and training activities to mutual learning and engagement between mentor and trainee. An early tutoring system for delivering instrumental lessons is the *Piano Tutor* (Dannenberg et al., 1990), already discussed in Sect. 1.3. More advanced tutoring systems benefit from various forms of visualization and feedback: articulation and dynamics (Knight et al., 2012); comparison of students' performances to a piano-roll score a (Tambouratzis et al., 2008); or comparison between expert and student audio files (Yin et al., 2005).

2.1.3 Constructivism

Strictly speaking, *Constructivism* is not a theory but, rather, a philosophical construct about the nature of learning (Hyslop-Margison and Strobel, 2007). *Constructivism* rejects the idea that learning is a transfer of theoretical assumptions to be verified and tested, but rather supports the concept that learners themselves are the creators of their own knowledge (Geary, 1995).

The first contribution to *Constructivism* comes from Piaget's theory of cognitive development, which establishes that learning happens in a sequence of stages: sensorimotor, preoperational, concrete operational, and formal operational. Each stage defines how children interact with the world and acquire the information needed to make sense of their environment (Piaget, 1952).

Another important contribution can be found in Vygotsky's sociocultural theory which emphasizes the social environment as a facilitator of development and learning. His *Zone of Proximal Development* (ZPD) theory describes the dynamic relationship between student and teacher. The student's task must be neither too simple to be accomplished alone nor too difficult to require the constant presence of the teacher. The ZPD is optimal when the teacher can provide only a final hint to let the student accomplish the task (Vygotsky, 1978). Another aspect is *activity theory*, which originates from the work of Vygotsky and was further developed and popularized by Leont'ev (1981). Activity theory explains how learning happens through the interaction of a subject, namely the learner, with an object to be learned, mediated by a tool supplied by the teacher and by a collaborative environment (Jonassen and Rohrer-Murphy, 1999).

[1] https://inagrm.com/en/showcase/news/203/acousmographe.

Another aspect is activity theory, which originates from the work of Vygotsky but has been further developed by the Russian psychologist A. Leónt' ev (1981). Activity theory explains.

Constructivism has important instructional implications, which engage teachers and learners in dynamic and stimulating relationships. *Discovery learning* is one: the process of discovery involves making and testing hypotheses and using inductive reasoning to extend the study of single examples to general rules and concepts (Bruner, 1961). *Learning through playing* may be considered an instance of discovery learning, as it involves some fundamental tenets of *Constructivism* such as cognitive dissonance, application of new knowledge with feedback, and reflection on learning (Baviskar et al., 2009).

Inquiry teaching, another form of discovery learning, is based on the Socratic teaching method of making questions and stimulating answers aimed at augmenting critical thinking (Collins and Stevens, 1983). *Peer-assisted learning* in the forms of *peer tutoring* and *cooperative learning* provides collaboration among students and participation in achieving tasks that are too complex for individual learners. *Reflective teaching* engages teachers in a continuous critical evaluation of their actions, strategies, student motivation, and results. Being aware of context, making fluid plans, and carrying out actions aimed at professional growth are the main characteristics of the reflective teacher (Savage et al., 2006).

With the richness and variety of its theoretical background, *Constructivism* represents the most popular framework in the design of instructional computer applications. A striking example of instructional technologies applying a constructivist approach is provided by the already mentioned *MicroWorlds* based on the *Logo* language (Papert, 1987), and the *Scratch* visual programming language. All the related musical applications discussed in Sect. 1.3.1, such as *Tuneblocks* (Bamberger, 1979) or the Scratch Music Projects by Brown and Ruthmann (2020), are designed to stimulate active exploration and learning through play. More in general, it may be stated that a constructivist approach in music learning activities is naturally focused on creative activities (composition, improvisation, orchestration, etc.) rather than on instrumental performance, and on the affordances offered by technologies in the carrying out of these activities.

For a constructivist approach to take place, the traditional classroom should be transformed into an adaptive learning environment endowed with integrated musical networks, new forms of musical participation, and innovative technological practices (Burnard, 2007; Hoover, 1996).

A shift in the role of the teacher is also required. As the student is now put at the center of the learning process by fostering ownership and motivation, the teacher cannot be a mere dispenser of knowledge anymore and is called into play in a more direct way. First of all, it is the teacher's responsibility to provide the students with rich authentic learning environments where they can explore multiple outcomes and have opportunities for receiving the teacher's guidance (Wiggins et al., 2006). According to Vygotsky's ZPD theory, the teacher's scaffolding activity provides guided participation that brings the learner to achieve a result otherwise impossible to obtain. Secondly, the teacher is called to re-frame assessment methods. Peer assessment in the form of peer grading or peer review may be considered a kind of learning activity in itself (Lebler, 2008). McConville (2021) outlines the potential benefits of peer review in music theory and composition classes in that it anticipates the judgments that the public could express in the future, putting to test at the same time students' abilities in evaluation, written communication, and fluency with relevant technologies.

2.2 Learning Theories and Instructional Technologies

It is useful to organize and classify instructional technologies in light of the learning theories summarized in the previous section. To this end, this section introduces the concept of cognitive tools in the context of digital technologies. Together with programmed instruction and intelligent tutoring systems, already examined in Chap. 1, cognitive tools can be considered to constitute the three main approaches to CAI in general and music learning technologies in particular, and can be mapped into different regions in the intersection of learning theories.

2.2.1 Cognitive Tools

Originating from the learning philosophy of Vygotsky (1978), the term cognitive tools refers to a set of cultural functions that mediate between instruction and cognitive development in the learning process, such as written language and mathematical notation. The concept can be extended to the potentialities offered by digital technology, considering computers not only as knowledge amplifiers but also as tools for mind reorganization (Pea, 1985). Thus, in a technological context cognitive tools include visualizations, metaphors, hypermedia, interactive interfaces, templates, databases, simulations, games, and collaborative media (Pakdaman-Savoji et al., 2019).

According to Jonassen and Reeves (1996), the idea of cognitive tools implies a shift between a view of computers as tools for educational communication to a view of computers as generators of learning environments that foster critical thinking and high-order learning. Learning is not the transmission of a standardized interpretation of the world, but rather the process through which learners construct meaning from what they experience of the world.

Cognitive tools help learners in this task because they are under the control of the learners themselves, who are engaged in the creation of knowledge that reflects their own understanding of the information. Cognitive tools do not distribute prestored knowledge but rather they enable forms of partnership and shared cognitive processing. Examples of cognitive tools analyzed by Jonassen and Reeves (1996) are provided in the remainder of this section.

Programming languages include statements for defining *repetitions* (loops), *selections* (decisions), and several data structures (arrays, lists, dictionaries, etc.). Programming is more than mere coding (Lye and Koh, 2014), as it helps exercise the abilities of problem-solving, problem decomposition, and logical reasoning. These are often collectively grouped into the definition of computational thinking, which is considered one of the fundamental skills for the 21st Century (Mohaghegh and McCauley, 2016). Popular programming languages for music are the visual, dataflow-oriented *Max*[2] and *Pure Data*,[3] which can be also used to foster computational thinking in music students (Manzo, 2016; Mandanici and Spagnol, 2023).

Hypermedia and multimedia systems are information delivery systems where text, images, videos, and audio can be combined together through a structure composed of nodes and links that can be freely navigated by the learner (Nelson, 1989). Organizing hypermedia communication envisions the learning process as knowledge construction rather than knowledge transmission. It requires project management, research, organization and representation, presentation, and reflection skills (Carver et al., 1992). Hypermedia for music education became popular with the appearance of many CD-ROMs such as *Music Mentor*[4] starting from the late 80s. Music can particularly benefit from hypermedia presentations because it is intrinsically multimodal. As an example, audio may be effectively combined with the visualization of an interactive score (Way and McKerrell, 2017). Piano-roll visualizations (see Sect. 1.3.2), spectrograms (Thibeault, 2011), and other multimodal representations of musical contents help students to see aspects that are emphasized by standard music notation and can even introduce them to formal studies in a more natural way (Schmidt-Jones, 2018). A study by Berz (1995) about the modalities by which users explore musical hypermedia environments shows that learners actually use different navigation strategies depending on their different aims.

Semantic networks represent meaningful relations between concepts graphically expressed by a series of boxes or circles connected with arrows. These knowledge representations are also known as concept maps that are relevant in the learning process because they require clarity in the knowledge of the learning material, relevant prior knowledge, and willingness on the part of the learner to learn in a meaningful way (Novak and Cañas, 2006). The term *semantic web* extends the idea of a semantic network to the affordances offered by the WWW, where data from different sources can be connected through automated semantic queries (Berners-Lee et al., 2001). An example of a free-form semantic network is depicted in Fig. 2.1. Passant and Raimond (2008) employ semantic web technologies to retrieve data from social music networks to provide information for music recommendation systems. Other examples of semantic networks for music information retrieval are reported by Baratè and Ludovico (2016).

Expert systems can simulate the role of a human teacher in assuming intelligent decisions about the learning process. Their role as cognitive tools has been

[2] https://cycling74.com/products/max.

[3] https://puredata.info/.

[4] https://winworldpc.com/product/music-mentor/1x.

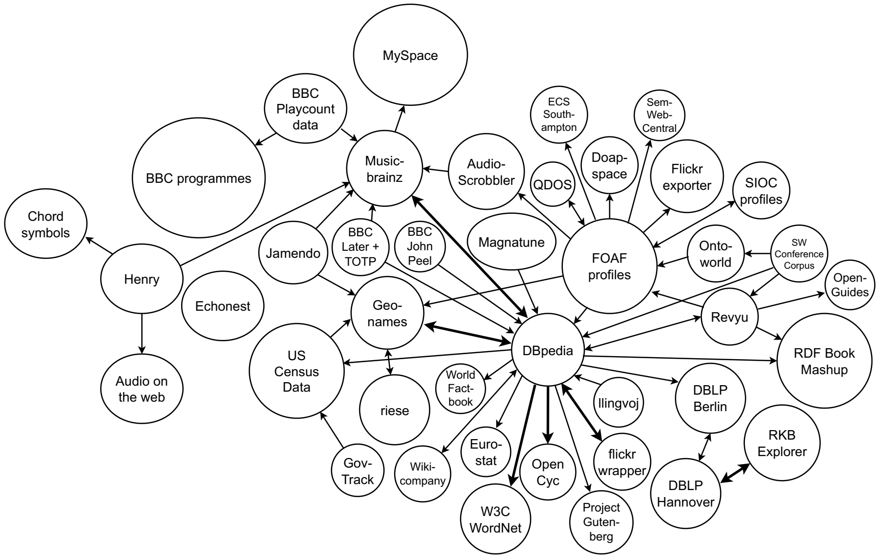

Fig. 2.1 An example of a free-form semantic network representing the relationships among various music datasets. Image adapted from Passant and Raimond (2008)

tested by Morelli (1990) who experimented with the learning effect of making the students themselves design an expert system for botanical classification. Assuming the responsibility of a knowledge engineer is not an easy task for students and, for this reason, little experimentation has been carried out in the field. Actually many expert systems exist for training music theory (Phon-Amnuaisuk and Siong, 2008) or music performing abilities (Pérez-Gil et al., 2016; Lin and Liu, 2006). However, these systems do not support a simple question-answer mechanism but are based on more complex interfaces and performance comparison systems. As such they are too complex for being implemented by students. Nevertheless, simpler approaches could be taken as an example, such as the simple ear training application suggested by Manzo (2016). Here the author, using *Max*, shows a step-by-step process for the construction of a small expert system for the recognition of musical intervals.

Databases are collections of structured data stored in a computer system similar to archives or libraries. They are a fundamental source of information that requires an active role by users. To benefit from a database users must identify the content domain, be aware of the structure of the database, and find meaningful keywords that better fit the query. Examples of music databases are *MusicBrainz*,[5] an open music database that collects metadata and makes them publicly available; *Freesound*,[6] a collaborative platform that offers a collection of audio files freely downloadable from

[5] https://musicbrainz.org/.
[6] https://freesound.org/.

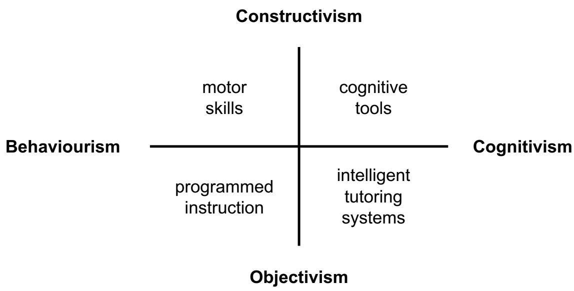

Fig. 2.2 Two-dimensional representation of learning theories and approaches to computer-assisted instruction. Image adapted from Jonassen (1992)

the users; *Choral Public Domain Library*,[7] a huge digital archive of choral music; and *IMSLP – Petrucci Music Library*,[8] an archive of classical instrumental scores.

2.2.2 A General Picture

Many scholars agree upon the fact that learning is a very complex process that cannot be simply labeled under a unique theoretical approach. Illeris (2018) argues that learning is composed of the union of external interaction between the learner and the environment and of internal psychological elaboration. While *Behaviorism* and *Cognitivism* focus on internal elaboration, other theories are more concerned with external interaction. However, this does not mean that these theories are invalid, but simply that they are unable to explain the entire learning process.

Jonassen (1991) contrasts learning – and more in general cognitive – theories along a different dimension. Some theories are grounded in the philosophical position that thinking is effective and can be studied only if it describes an objective reality, which learners must understand and incorporate (Lakoff, 1988): this position is referred to as *Objectivism*, and is contrasted to *Constructivism*, which considers reality as an autonomous interpretation of the learner's mind (Bruner, 1961).

Based on these considerations, it is possible to arrange learning theories in a two-dimensional representation, where one axis spans the two opposed psychological constructs of *Behaviorism* (no participation of the mind in the learning process) and *Cognitivism* (learning as information processing), while the second axis is associated to the two opposed epistemological constructs of *Constructivism* and *Objectivism*. Such a representation provides a structured and semantically meaningful space, in which different approaches to computer-assisted instruction can be situated.

Specifically, Jonassen (1992) proposes the representation depicted in Fig. 2.2. **Programmed instruction** is placed in the Behaviorism/Objectivism quadrant, as it not only relies on behavioristic principles such as question/answer mechanisms, repetition, and rewards for positive reinforcement but also treats knowledge as objective,

[7] https://cpdl.org/.

[8] https://imslp.org/.

externally mediated information which the learner has to acquire, to assimilate from the teacher. **Intelligent Tutoring Systems** are placed in the Cognitivism/Objectivism quadrant: from the one hand, they represent a more advanced learning technology as they provide a transition from a behavioristic to a cognitivistic learning approach (in particular, they embody the social Cognitivism theory of learning from a tutor), but, on the other hand, they maintain an objectivistic view of knowledge and learning.

Cognitive tools are instead placed in the upper half-plane, precisely in the Cognitivism/Constructivism quadrant, as they assume the cognitive processes of the mind, but they aim at provoking reflective learning rather than obtaining objective knowledge: they engage the learner in element discovery and experimentation and are learner-centered because the learner obtains information through her/his own experience. Finally, **Motor skills** are also mentioned in Jonassen's representation and occupy the Behaviorism/Constructivism quadrant, however, no discussion regarding this positioning is provided by the author.

At the end of his analysis Jonassen (1992) concludes that it is unrealistic to think that all knowledge is personally constructed. Learners must negotiate their knowledge with society, conventions, and common schemas that emerge from the environment and culture. Although most of the instructional technology is inspired by *Objectivism*, however, designers should also consider the potentialities of the constructivist approach and make the best choice depending on the context. Cronjé (2006) also supports the integration of the objectivistic and constructionist approaches, the first aiming at direct instruction, the second at providing a richer learning experience. In fact, the learning experience is composed of both processes and both must be taken into account in the instructional design.

2.3 New Learning Contexts and Environments

The great number of tools and technologies available for teaching can create very rich and varied learning contexts and environments. Teaching today is not only a matter of organizing materials for frontal lessons in a classroom but of experimenting with many other educational approaches mediated by technology. In contexts such as those described by Burnard (2007) the teacher is asked to organize exploration activities and to foster collaborative learning and experience sharing, a much richer and differentiated approach with respect to the traditional frontal lesson. New network technologies and the availability of portable devices make learning happen in many places, also outside schools and other formal contexts. This challenges teachers in revising their strategies and in introducing innovation in their practice (Garzon Artacho et al., 2020).

This section focuses on the most relevant changes in the relationship between students and teachers and between students and knowledge related to the use of technology. The aim is to outline the main learning situations that a student may face in a technological environment. Pedagogical aspects, and their implications for music learning, are presented and analyzed starting from the ever-increasing coexistence

Table 2.2 Characteristics of Formal and Informal Learning. Table adapted from Cross (2007)

Formal learning	Informal learning
Is accomplished in school, courses, workshops, etc.	Can happen everywhere
Is scheduled in advance	Is not programmed and can happen both intentionally and inadvertently
Realizes a curriculum	Considers learning as an open-ended activity
Requires that learners are evaluated and graded	Assigns no grade since success in life is the measure of effectiveness

of formal and informal learning in students' experiences (Sect. 2.3.1). Aspects of online learning theories are described in Sect. 2.3.2. Section 2.3.3 is dedicated to blended learning, a teaching approach where the use of online or other computer technologies is mixed with the traditional face-to-face lesson modality. All these different approaches draw a composite picture where technology opens the way to a multidimensional character of music teaching and learning.

2.3.1 Formal and Informal Learning

Formal and informal learning are defined by Cross (2007, p. 12) not as dichotomies but rather as ranges along a continuum of learning, as most learning experiences are a blend of both aspects. Distinguishing characteristics of the two extremes of the continuum are outlined in Table 2.2.

According to Folkestad (2006), in formal music learning, activities are scheduled in advance and their sequence is defined by the teacher, while, in informal music learning, the activity is steered by events (social interactions, creative processes, accidental discoveries) that occur during the experience. Four ways of defining formal or informal music learning are identified:

1. **situation**, i.e. the physical context (e.g., in the classroom or outside the school);
2. **learning style** (e.g. playing by written music or by ear);
3. **ownership**, i.e. who decides what to learn and where (e.g., didactic teaching or self-regulated learning);
4. **intentionality**, i.e. the aims towards which the mind is directed (e.g., learning how to play an instrument or just playing it).

All these elements must be regarded in a dynamic way. As an example, formal learning and informal learning do not necessarily happen only inside the classroom or outside the school, respectively, as learning depends on intentionality, which is not affected by a specific location. Formal learning is not even tied to specific music genres (e.g., classical music learned through established methods and materials), nor does informal learning apply exclusively to popular music learned by ear.

Finally, Folkestad (2006) observes that learning can be formal or informal, but teaching is always formal by its nature. However, teachers can embed in their programs situations where informal learning can happen and can help transform their pedagogical framing according to student progress. In particular, since younger generations are deeply engaged from a very early age in the use of technologies for listening, creating, and sharing music, employing the same technologies in the classroom links informal learning activities that belong to the student's experience to teaching activities. Many different software environments have been employed for this purpose, such as *Drumsteps* and *Hyperscore* (Jennings, 2007), *Dance eJay* (Mellor, 2008), *JamMo* (Paananen and Myllykoski, 2009) and *Sibelius Groovy Shapes* (Charissi and Rinta, 2014).

2.3.2 Online Learning

Since the beginning of WWW 2.0 (see Sect. 1.4), the main concern of designers was to avoid the mere reproduction of traditional teacher-centered class features, but rather to conceive new learning contexts going beyond the face-to-face class (Turoff, 1995, p. 1).

As discussed in Sect. 1.4.2, online learning environments employ various methods and functionalities to deliver information and foster interaction (Singh and Thurman, 2019).

Online learning environments build communities where students can shape and share their knowledge through autonomous investigations and peer-to-peer learning. Collaborative workspaces in particular support the shift from an objectivist learning model – where the teacher transmits to learners an already consolidated wealth of information – to a constructivist learning paradigm where learners are the architects of their own knowledge (Jonassen et al., 1995). Keast (2009) suggests some guidelines for teaching music theory, history, and appreciation through online courses based on a constructivist approach. These include the availability of online materials (scores, audio, and video) to allow students to investigate the topics independently, as well as tools for collaboration and self-assessment.

All the applications for collaborative music making discussed in Sect. 1.4 provide good examples of this approach in the musical domain (Seddon, 2006; Ng et al., 2007), as well as online music communities, social platforms, and online communities of practice, also examined in Sect. 1.4. Communities of practice and social networking platforms share the same key working principles: participation, presence, and ownership. Salavuo (2008) claims that the same key ideas should also support the design of online music education platforms, which should abandon models where consolidated knowledge is distributed by an instructor in favor of learner-centered education.

An important effect of online music learning is the diversification of music education environments, which are no longer restricted to European music of the 18th and

19th centuries, but can be extended straightforwardly to other genres. This enhances the promotion of cultural diversity and the openness toward cultural minorities (Ruthmann and Hebert, 2012).

2.3.3 Blended Learning

According to Graham (2006), blended learning systems combine face-to-face instruction with distributed, online instruction. As such, they also combine the main features of face-to-face environments (real and high-fidelity human-to-human interaction) with those of online learning environments, as discussed above: online learning is distributed, self-paced, asynchronous, and puts emphasis on interactions between learners and materials. Under the pressure of communication technologies, the boundaries between these two approaches are rapidly thinning. Computer-supported collaboration, virtual communities, and instant messaging provide an additional degree of humanness to computer learning environments, thus partially replacing the traditional functions of the teacher.

The blended learning approach may include the following activities (Jenkins and Crawford, 2016):

- the use of electronic devices in the classroom (laptops, smartphones, tablets);
- the creation and use of online communities for sharing ideas, activities, and materials;
- a synergy between computer and online resources and classroom activities;
- real-time posting of classroom discussions and activity materials;
- encouragement for students to share resources.

In addition, blended learning implies a change in time and places where activities occur. Watson (2008) defines blended learning as a shifting segment along a continuum that starts from a face-to-face setting with few or no online and technological resources available (the traditional classroom) and arrives at a fully online curriculum with all learning done outside the classroom and with no face-to-face component. In between, degrees of integration can range from traditional face-to-face to fully online instruction. Action places shift from the classroom through the computer lab to everywhere; learning moments shift from the curricular lesson times through selected days in the classroom and in the lab to every time. The use of everyday spaces is studied in ubiquitous music (*ubimus*), an area of research that lies at the intersection of ubiquitous computing and music (Keller et al., 2014).

Online music learning environments can be also embedded within regular school programs (Crawford, 2017). The literature reports case studies of group music composition in a blended learning environment (Ruokonen and Ruismäki, 2016) as well as the development of a participatory learning culture obtained by coupling face-to-face activities to an online discussion platform in a music technology class (Draper and Hitchcock, 2008).

Bowman (2014) provides the reader with theoretical frameworks and practices for online music learning in higher education, together with useful references for designing online music courses. King et al. (2019) compare digitally-delivered and face-to-face instrumental lessons to explore the differences in behavior, while Johnson (2020) outlines the need to adjust teaching styles to the online condition by applying a constructionist approach (creativity and discovery).

2.4 Summary

This chapter offered an overview of the three main learning theories and their applications for computer-supported music education. The first and older theory is Behaviorism, which is grounded on the research on animal behavior started in the late 19th century by Thorndyke and Watson. Behaviorism has been later developed by Skinner with his theory of *operant conditioning* (1938) which in 1958 gave birth to *programmed instruction*. Around the 60s, a big wave of criticism began to challenge Behaviorism, mainly due to its view of learning as a passive and mechanical response to external stimuli. As an answer, the theories of *Social Cognitivism* by P. Bandura (1986) first and then of *Constructivism* offered a broader vision of learning. *Cognitivism* emphasizes the way the brain processes information and the importance of the observation of gestures, skills, and strategies from other people in the learning routine. *Constructivism* stresses the importance of the learner as the builder of her/his own knowledge by proposing instructional practices such as *discovery*, *cooperative learning*, and *inquiry teaching*. Contemporary technologies produce new learning contexts and approaches. Fueled by the wide availability of online platforms and tools, *informal learning* is now an integral part of the student's educational experience, while *online* and *blended learning* define new borders and modalities to learning activities.

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Chapter 3
Organizing Technology-Mediated Music Learning

Abstract In this chapter, frameworks and tools useful to organize the complex world of technology-mediated music learning are analyzed. Focusing mainly on the TPACK framework, where pedagogy, technology, and content information complement each other, an organization of knowledge in the musical domain is also proposed. The analysis of the three artistic processes (creating, performing, and responding to music) is fundamental for classifying musical activities and, in light of these findings, new programs for the professional training of music teachers may be proposed. Finally, some approaches for embedding technology in music curricula are presented and discussed.

3.1 Technological Pedagogical and Content Knowledge (TPACK)

Starting in 1986, the American educational psychologist L.S. Shulman began to emphasize that while cognitive psychology has focused on the understanding of learning processes from the student's perspective, much less attention has been devoted to understanding how teachers acquire the knowledge required to manage educational activities (Shulman, 1986). Questions about how to organize materials, how to present them, and how to carry out assessment activities remained largely ignored by research at the time.

A good teacher has to master the fundamental notions of her/his subject (content knowledge), but at the same time has to know how to motivate students, how to engage them in overcoming difficulties, and how to offer them a framing perspective of the newly acquired information (pedagogical knowledge). In his work, Shulman rejected the idea that these two fields contribute in a mutually exclusive fashion to the teacher's knowledge. Instead, he introduced the notion of "Pedagogical Content Knowledge" (PCK), which combines the two in the form of knowledge integration. According to Shulman, PCK corresponds to *[…] the most useful forms of representation of the most powerful analogies, illustrations, examples, explanations, and*

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demonstrations—in a word, the ways of representing and formulating the subject […] that make it comprehensible to others (Shulman, 1986).

These ideas influenced subsequent teachers' pre-service curricula (Grossman, 1990) and aroused the interest of researchers in the process of building pedagogical knowledge (Mecoli, 2013). However, the most influential aspect of Shulman's work is the idea of knowledge integration, which brings together two forms of knowledge fields and produces as a result a third, brand-new form. Building on these ideas, Koehler and Mishra (2009) added the technological dimension and proposed the *Technological Pedagogical and Content Knowledge* (TPACK) conceptual framework.

The TPACK framework emphasizes that using technology effectively for educational purposes requires not only understanding technological means and how they work, but also being able to see and interpret the dynamic relationships between technology, content, and pedagogical knowledge.

3.1.1 Types of Knowledge

The forms of knowledge considered in the TPACK framework are summarized in Fig. 3.1. There, the contents of the three primary forms of knowledge (CK, PK, and TK) are paired to generate three new secondary forms (PCK, TCK, and TPK). TPACK is the result of the overlapping of all three forms.

The three primary forms are:

- **Content knowledge (CK)** is the extensive knowledge of the subject to be taught. Usually, teachers should have knowledge corresponding to their degree in the subject, excluding pedagogical skills. In music this means that teachers should have knowledge of music theory and history, as well as have developed listening, playing, composing, and improvisation skills.
- **Pedagogical knowledge (PK)** corresponds to the seven categories outlined by Shulman (1986), namely (i) organization in preparing and presenting instructional plans, (ii) evaluation, (iii) recognition of individual differences, (iv) cultural awareness, (v) understanding youth, (vi) management, (vii) educational policies and procedures. These can be complemented by the knowledge of learning theories and psychological foundations of learning.
- **Technological Knowledge (TK)** strictly speaking is the knowledge of any technology for teaching and learning. In the digital domain, it goes beyond traditional notions of computer literacy and requires that teachers understand information technology broadly enough to apply it productively information processing, communication, and problem-solving, as well as to continually adapt to changes in information technology, in an open-ended fashion.

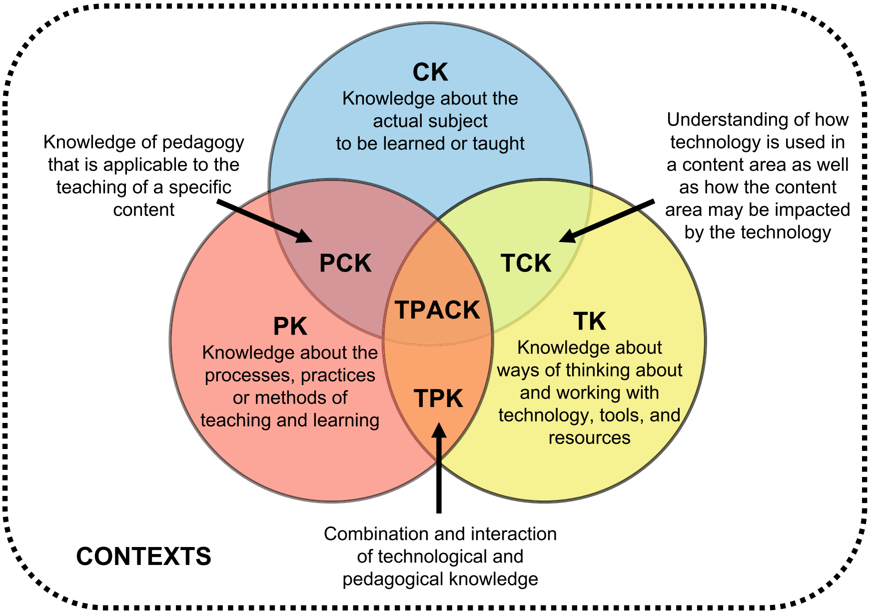

Fig. 3.1 Technological pedagogical and content knowledge with the three forms of primary and secondary knowledge obtained by overlapping content knowledge, pedagogical knowledge and technological knowledge. Image adapted from http://www.tpack.org/

The three secondary forms are:

- **Technological Content Knowledge (TCK)** is the knowledge of the ways in which technology and content influence and constrain one another, including the manner in which the subject matter can be changed by the application of certain technologies, as well as which technologies may be best suited for aiding learning in a given domain. In the realm of digital music, TCK may range from the use of MIDI instruments and controllers to the ability to set up an audio system, from the knowledge of tools and techniques for audio recording to the ability to run a DAW or to use music programming languages. Moreover, a basic knowledge of acoustics, sound synthesis techniques, and interfaces for music production could enrich the gamut of possibilities for proposing interesting music technology activities.
- **Pedagogical Content Knowledge (PCK)** is knowledge of pedagogy that is applicable to the teaching of specific content, allowing the teacher to transform the subject matter for teaching, find multiple ways to represent it, and adapt and tailor instructional materials to alternative conceptions and students' prior knowledge. In music, PCK is the ability to combine musical knowledge with methods and strategies for teaching.

  The history of music pedagogy offers many approaches (Houlahan and Tacka, 2015; Findlay, 1995). Particularly the American edition of the Orff Schulwerk (Orff, 1977a, b, c) proposes many interesting activities ranging from music games, physical activities, reactions to auditory stimuli, and instrumental and vocal improvisations. Differently from the original Schulwerk, the American Edition benefits from multiple contributions, coming from its different musical cultures.

- **Technological Pedagogical Knowledge (TPK)** is knowledge of how teaching and learning can change when specific technologies are used in certain ways and requires an understanding of the constraints and affordances of technological tools, as well as their relation to appropriate pedagogical designs and strategies.
  Contemporary technologies for learning may be multimodal presentations (Moreno and Mayer, 2007), interactive simulations (Vogel et al., 2006), digital learning environments (Peters, 2000), digital games (Gros, 2007), MOOCs (Baturay, 2015), large-scale interactive environments (Mandanici et al., 2018) and customized web platforms (Yau et al., 2009), which are largely employed also for music education.

Finally, the **Technological, Pedagogical and Content Knowledge (TPACK)** represents the new form of knowledge that is generated by the overlap of the 3 secondary forms. Any educational project that includes the use of digital technologies requires a change in the instructional approach and an evolution in the goals to be reached.

In Fig. 3.1, the "Contexts" label surrounds the whole diagram to indicate the situated nature of TPACK, which is a flexible framework compliant with physical constraints (classroom, laboratory, equipment) as well as cultural constraints (class level, course aims, students' attitudes, and so on).

3.1.2 Content Transformation: The SAMR Model

The interactions between the three primary forms of knowledge described in the TPACK framework may lead to a significant impact on the content itself. This is especially expressed in the secondary form TCK, describing the interrelation between content and technology. This process of content transformation is well formalized by the *Substitution Augmentation Modification Redefinition Model* (SAMR), which envisions four levels of content transformation resulting from the use of technologies (Hamilton et al., 2016).

1. **Substitution** refers to the case when digital technologies are employed instead of traditional means, without functional changes. An example in music education may be employing music notation software instead of paper and pencil for writing music. At this level, there is no change in the content.
2. **Augmentation** occurs when digital technologies are still employed as a substitute for traditional means, but, in this case, the function of the task changes in some way. Sticking to the previous example, augmentation may refer to the appreciation of the advantages provided by the use of notation software (tidy writing, uniform bar and stave spacing, etc.). There is an improvement in the score presentation, but still no inner changes in the content.
3. **Modification** refers to the case when technology integration requires a significant redesign of a task. As an example, the novel means of interaction offered

by the music notation software start to be exploited, including the possibility of copying and pasting musical phrases, transposing and cutting them, and so on. Here the content begins to be modified thanks to the opportunities offered by the technology.

4. **Redefinition** is achieved when the technology is used to create novel tasks, which would not be conceivable using traditional means. Using music notation software, the various materials of the musical composition can be freely re-adapted by the user in a much simpler way than if they were written on paper: new musical ideas can be introduced by playing them on a MIDI keyboard, and the user can experiment with the musical form by moving different sections of the composition, by changing their speed, timbre, and dynamics.

Even more dramatic changes are possible if, instead of notation software, the teacher introduces the students to the possibilities of a music programming language. The problem with these transformations is that they lay in an area that usually is outside teachers' experience. Traditional musicians are very strongly tied to consolidated practices, learned during years of work. This makes music teachers very resilient to changes, mainly if they lack innovative pedagogical and artistic models.

3.1.3 Integrating TPACK into Music Teacher Curricula

In the context of music education, the TPACK framework emphasizes different aspects of knowledge integration, which comprise not only traditional music education mediated by technology but also pedagogical approaches to contemporary digital music technologies. The musical content—mediated by technology—needs to be introduced by appropriate pedagogical methods.

Bauer (2014) underscores the gap that still exists between the instructional potential of technology and what is actually taking place in classrooms, which can be attributed not only to the lack of resources and technical support but also to insufficient professional development offered to teachers to acquire the pedagogical understanding necessary for effectively integrating technology into their educational practice. When technology was introduced in schools it was a common belief that teachers would find themselves the right ways to embed the potential of the new tools in their curricula. But very soon it was recognized that installing computers in schools is not enough (Cuban, 2001), and that teachers should be provided with the necessary technological background (Gall, 2013) and offer them the possibility of discovering the real potentialities of technology integration in their teaching practice (Greher, 2011).

TPACK outlines a rich and varied knowledge structure for teachers who, beyond being experts in traditional music curricular knowledge and abilities, should also demonstrate proficiency in the use of digital technologies for music. This raises the question of how to design a proper curriculum for teachers to respond to such needs. As Koehler and Mishra (2005) point out, simply embedding music technology workshops in the curriculum of pre-service music educators is not enough to provide the awareness and the ability to apply technology in educational practices (Brand, 1998; Duran et al., 2006; Haning, 2016). Teaching technology by design is the best way to make TPACK effective, but it requires a high level of ability in managing the rich context provided by this factual approach (Koehler and Mishra, 2009). By contrast, the reality reported by research in the field is that the main obstacle to the use of technology in schools is simply that teachers are not prepared to use it (Dorfman, 2016a). The authenticity of integration, lack of administrative, technological, and pedagogical support, limited access to technology and/or funding, and lack of space in the curriculum are reported among the main obstacles met by teachers (Bakir, 2015; Bauer and Dammers, 2016; Dorfman, 2016b; Eyles, 2018). However, teachers' competencies in the use of digital materials remain the main impact factor for the integration of technology in the classroom (Trainin et al., 2018; Wise et al., 2011) and, for this reason, music technology training programs in pre-service curricula are strongly recommended (Bakir, 2015).

3.2 Artistic Processes

In order to find effective ways to organize content related to music learning and education, it is helpful to look at previously proposed standards for education in the arts.

Developed by *NCCAS* (National Coalition for Core Arts Standards),[1] the last version of the National Core Arts Standards was released in 2014.[2] The aim of the standards is to identify the knowledge that each student must achieve in the artistic field, thus helping teachers in developing and organizing their own teaching programs. The standards derive from the observation of the artistic processes through which artists communicate with their audience and with the society around them. The standards are cognitive and physical actions through which art is realized and, consequently, represent a reliable link between art making and the learner (National Coalition for Core Arts Standards Archives, 2014).

The 9 standards outlined in Table 3.1 are grouped into the 3 broad areas of artistic processes, namely "Creating", "Performing", and "Responding". According to Shuler (2011), artistic processes are also compliant with the so-called *four Cs* model because they support:

- *creativity*, by suggesting to students to engage in improvisation, composition, and interpretation of music;
- *critical thinking*, by suggesting to students to select music pieces, refine performances and compositions, and interpret the intent and meaning of music;

[1] NCCAS is an alliance of national arts and arts education organizations that formed in 2011 and is dedicated to the work of creating and supporting national arts standards (https://sites.google.com/nccas.org/nccas-wikispace).

[2] https://www.nationalartsstandards.org/.

Table 3.1 Artistic processes definitions and standards. Table adapted from National Coalition for Core Arts Standards Archives (2014)

Artistic processes	Definitions	Standards
Creating	Conceiving and developing new artistic ideas and work	1. Generate and conceptualize artistic ideas and work 2. Organize and develop artistic ideas and work 3. Refine and complete artistic work
Performing	Realizing artistic ideas and work through interpretation and presentation	4. Select, analyze, and interpret artistic work for presentation 5. Develop and refine artistic techniques and work for presentation 6. Convey meaning through the presentation of artistic work
Responding	Understanding and evaluating how the arts convey meaning	7. Perceive and analyze artistic work 8. Interpret intent and meaning in artistic work 9. Apply criteria to evaluate artistic work

- *communication*, by teaching students to communicate while performing or composing music, or while expressing their musical ideas during the "Responding" process;
- *collaboration*, by fostering group decisions through student-directed sectionals, chamber ensembles, and collaborative composition groups.

Although the National Core Arts Standards were released for the United States, most standards for arts education in other countries seem to build on the same three areas (Australian Curriculum, 2015; Education Bureau of the Government of the Hong Kong Special Administrative Region, 2003; UK Department of Education, 2013; Government of Ireland, 1999). Thus, the framework of "Creating", "Performing" and "Responding" may be considered a sound and widely shared system for organizing artistic knowledge and educational activities.

3.3 Embedding Technology in Music Curricula

The National Core Arts Standards provide a useful framework for embedding technologies in music curricula. In particular, Rudolph (2004) maintains that the simplest way to build a music curriculum based on technology is to combine the potentialities of available technologies with the music activities defined by these standards. His ideas, which are actually grounded on a previous version of the Standards released

Table 3.2 Some ideas for connecting technology to the Music Standards (Mahlmann et al., 1994). Table adapted from Rudolph (2004)

Standards (1994)	Devices and software	Activities
1. Singing, alone and with others, a varied repertoire of music	MIDI keyboard and sequencing software	Create, record, and playback accompaniments
	Claire and Audio Mirror software	Analyze the singing voice and receive feedback to improve performance
2. Performing on instruments, alone and with others, a varied repertoire of music	Electronic keyboards	Play bands or various ensembles replacing missing instruments
3. Improvising melodies, harmonies, and accompaniments	MIDI keyboard and sequencing software	Play accompaniments while exploring improvisation
	Band-in-a-Box	Experiment with harmonies and accompaniments
4. Composing and arranging music within specified guidelines	Notation software	Compose and listen
5. Reading and notating music	Notation software	Create printed scores
	Computer-assisted instruction software	Recognize rhythm and tonal patterns
6. Listening to, analyzing, and describing music	Computer-assisted instruction software	Learn music theory and ear training
7. Evaluating music and music performances	MIDI keyboard and sequencing software	Playback of music pieces
	MIDI keyboard and notation software	Compare performances with the printed score
8. Understanding relationships between music, the other arts, and disciplines outside the arts	Electronic keyboards and multimedia software	Create and modify sounds, linking music with science and mathematics
9. Understanding music in relation to history and culture	CD-ROM	Listen to music with text, images, and videos

in 1994 (Mahlmann et al., 1994), are outlined in Table 3.2. The result is an effective and consistent operational framework. Even if the considered equipment is limited and outdated with respect to present days, the connections between standards, technologies, and activities are sound and clearly show the new possibilities offered by electronic devices and software.

A complementary approach is followed by Watson (2011), who starts from available technologies to propose a series of lesson plans aimed at enhancing students' creativity. The range of available devices and software comprises:

- electronic keyboards;
- sound recording applications;

Table 3.3 Bauer's taxonomy of music activities. Adapted from Bauer et al. (2012), Bauer (2014)

Artistic processes	Music activities	Activity types
Creating	Improvisation	1. Echo rhythm and tonal patterns
		2. Improvise a tonal or rhythmic answer to a tonal/rhythmic prompt
		3. Perform familiar melodies and/or their bass lines by ear
		4. Improvise rhythmic and/or melodic variations on a familiar melody
		5. Perform melodic patterns in a variety of keys/tonalities
		6. Improvise an original melody to a given accompaniment
		7. Transcribe a solo
		8. Improvise in a group
		9. Improvise an accompaniment
		10. Engage in free improvisation
	Composition	1. Create an ostinato
		2. Use non-traditional sounds to create music prompt
		3. Create or utilize an alternative notation
		4. Compose an "answer" phrase to a given "question" phrase
		5. Compose a melodic variation
		6. Compose using repetition and contrast
		7. Create a loop-based composition
		8. Create a remix
		9. Arrange music
		10. Compose an accompaniment
		11. Create a composition
		12. Compose a video soundtrack
Performing	Singing	1. Sing with a steady beat
		2. Sing with appropriate posture, breath support, and diction
		3. Sing individually
		4. Sing in an ensemble
		5. Sing with technical accuracy
		6. Sing with expression
		7. Listen to/view vocal/choral models
		8. Respond to the gestures of a conductor when singing
		9. Cover a song
	Playing	1. Play with a steady beat
		2. Play with appropriate posture and technical (motor) skills
		3. Play individually
		4. Play in an ensemble
		5. Play with technical accuracy
		6. Play with expression
		7. Listen to/view instrumental models
		8. Respond to the gestures of a conductor when playing
		9. Cover a song

(continued)

Table 3.3 (continued)

Artistic processes	Music activities	Activity types
	Reading	1. Clap/sing with rhythm syllables, sing/play varying rhythm patterns
	and notating	2. Sing with solfège syllables, sing/play varying pitch patterns
	music	3. Identify and interpret musical symbols
		4. Read standard notation while singing or playing
		5. Sight read accurately
		6. Aurally identify and/or notate patterns
		7. Notate music
Responding	Listening and	1. Listen repeatedly
	Describing	2. Listen to examples
		3. Guided listening
		4. Listen to, describe, and discuss music
		5. Listen and reflect
	Analyzing	1. Move in response to music
		2. Identify and label structural and expressive components of music
		3. Describe and discuss structural and expressive components of music
		4. Develop an analysis
		5. Develop an interpretation
	Evaluating	1. Develop criteria for evaluating a musical performance, improvisation, composition, or arrangement
		2. Critique a musical performance, improvisation, composition, or arrangement
		3. Provide constructive suggestions for improvement of a musical performance, improvisation, composition, or arrangement
		4. Create a musical portfolio

- multi-track music production applications;
- music notation applications;
- instructional software and other music applications.

Lesson plans are built upon a set of principles aimed at facilitating students' creativity. For each lesson plan, the corresponding national standards addressed are outlined as a reference framework for the various proposed activities.

The work of Bauer (2014) is particularly relevant in this domain because it builds on the three artistic processes of "Creating", "Performing" and "Responding" in order to produce a taxonomy of music activity types, summarized in Table 3.3. Although the set of included activity types is not exhaustive and may be expanded to include new forms of music making, the table shows the potential of this taxonomical approach.

Despite the fact that, in every music activity, these three processes are inextricably present at various degrees, Bauer et al. (2012) make an analytical effort to group activity types in each of the three areas, including technological facilities such as software, applications, and other instructional material.

Of a completely different nature is A. R. Brown's work, where the author widens substantially the field of available technologies and educational approaches (Brown, 2014). Here the focus is not on the artistic processes and music standards but rather on music technologies. Thus, audio recording theory and techniques, MIDI sequencing, algorithmic composition, sound synthesis, and live electronic music are presented in plain and clear language with the aim of delivering information to teachers interested in the topic. The review of the music technologies is integrated at the end of each chapter with reflection questions, teaching tips, and suggested tasks that offer some hints for organizing effective didactic units. The book also discusses how to integrate technology into the curriculum, and how to cope with related cultural differences that impact musical practice in various communities: by focusing on technologies rather than teaching approaches and contents, the author acknowledges that any digital music pedagogy should take into account cultural factors. Himonides and King (2016) further expand the landscape of the possibilities of music technology in education by including issues deriving from the practice in a contemporary music production studio, game technology, special education needs, and assessment, while (King et al., 2017) address themes like live coding, laptop orchestra, gender perspectives, and virtual worlds. A more recent contribution is *Practical Music Education Technology* (Dammers and LoPresti, 2020) a handbook for helping music teachers in planning their music education activities with technology. Beyond the traditional notation, audio recordings, and sequencing software, suggestions on the use of videoconferencing, online resources, and cloud computing are included.

3.4 Summary

Although a theory dedicated to the integration of technology in education, TPACK is also a representation of the various forms of knowledge that characterize contemporary teaching. For this reason, in this chapter, we have focused on analyzing both its theoretical and practical aspects. From a theoretical point of view, TPACK is the result of the integration of three different domains: content-related (i.e. musical), pedagogical, and technological domain. Moreover, for the musical domain, we rely on the three artistic processes of creating, performing, and responding, defined in 1994 and further reviewed in 2014. From a practical point of view, we have provided examples of how TPACK can inform pedagogical practice by presenting different approaches, perspectives, and strategies.

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Chapter 4
A Taxonomy of Digital Music Learning Resources

Abstract Previous chapters have reviewed the state of the art in digital music education, in terms of available technologies and their relation with learning theories, as well as conceptual frameworks for organizing technology-mediated learning. Based on this discussion, in this chapter, we propose a Taxonomy for Digital Music Learning Resources (TDMLR) aimed at serving as a theoretical instrument to investigate the multidimensional classification of resources, as well as a practical tool to help educators identify the most suitable approaches and applications described in the scientific literature depending on their needs.

4.1 Motivations and Overview

When observing the development of computer-supported music education from its beginnings (Kuhn and Allvin, 1967) to the present days, there is a clear tendency to move from closed and clearly focused learning environments to a highly fragmented supply of digital materials aimed at varied—and often open-ended—purposes. This is due in part to technological development, in part to the broadening of the field of action of technology-supported music education, and in part to the perspective shift of learning approaches due to the large availability of devices and connectivity.

As discussed in previous chapters, in the 1970s computers were very expensive, and educational systems could be set up only within large communities (firstly universities and then other kinds of schools). The educational design was largely inspired by programmed instruction, with the main target in music theory and ear training. Conversely, today we benefit from a large amount of distributed electronic devices, the possibility of internet access also through mobile devices, and a wider interest in music education, which is not only focused on technical achievement but also on the development of creativity (Webster, 2002), critical thinking (Kokkidou, 2013), scientific and computational reasoning (Perales and Aróstegui, 2021; Ruthmann et al., 2010). Thus designers are no more planning self-contained systems but rather target single applications aimed at particular aspects of music education. The gamut of possibilities is vast, technology offers many solutions for the same task, and end users

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range from children to adult professional musicians. This makes it very difficult for researchers and practitioners to keep track of what designers propose and experiment with in the field. What is missing is a general framework that could orient interested stakeholders by proposing meaningful reference criteria for the classification of the various digital materials.

A useful tool for properly representing knowledge fields characterized by a high level of complexity is provided by a *multidimensional taxonomy*, which consists of a number of associated dimensions belonging to different domains (Law et al., 1998). By applying this definition to the field of digital materials for music education, a multidimensional construct organized into three levels was elaborated.

The TPACK framework provides useful insights for the organization of technology-mediated music learning, substantially widening the perspective of the field and making it more in keeping with the needs of contemporary teaching. The integration of a content (musical) domain, a pedagogical domain, and a technological domain for the building of a new multifaceted knowledge domain is a very inspiring approach.

Therefore, we propose a Taxonomy of Music Digital Learning Resources (TDMLR hereinafter) in which the first level classification includes the three *Technological*, *Musical*, and *Pedagogical* domains, corresponding to the three primary forms of the TPACK framework. For each of these three domains, a set of dimensions is considered the second level of classification. Each dimension is in turn assigned a number of nodes, that can be used as tags for a specific contribution or application. The proposed dimensions and nodes are the result of an iterative process that included a detailed analysis of the literature. The resulting structure is summarized in Table 4.1. The organization of the three *Technological*, *Musical*, and *Pedagogical* domains is discussed in Sects. 4.2, 4.3, and 4.4, while the analysis of the related literature will be presented in further detail in Chap. 5.

In this section, the reference frameworks for each Domain are presented. The 10 Dimensions of the TDMLR derived from the analysis of the literature are explained and the Nodes are referenced with application examples.

In addition to the three main domains, the TDMLR also includes a Metadata domain, which is aimed at providing all the relevant information needed to uniquely identify a specific contribution or application. This includes the following 3 dimensions:

0.0. Material—This dimension reports the name of the application, if explicitly indicated in the publication; in another case, we assign the application a self-explanatory name followed by the label "(attr.)" to emphasize that the name is not original.

0.1. Contribution—This dimension indicates the type of research contained in the article. Concerning nodes, a scientific paper can be an Evaluation (description of the application and results of users tests), a Presentation (description of the application only), a Case study, a Review or Practices (teaching experiences or methods);

Table 4.1 The 3 levels of the TDMLR with their associated domains, dimensions, and nodes

1st Level: Domains	2nd Level: Dimensions	3rd Level: Nodes
0. Metadata	0.0. Material	0.0.0. Name
	0.1. Contribution	0.1.0. Evaluation 0.1.1. Presentation 0.1.2. Case study 0.1.3. Review 0.1.4. Practices
	0.2. Date	0.2.0 20xx
1. Technological	1.0. Applications	1.0.0. Desktop 1.0.1. VR, AR 1.0.2. Tangible computing 1.0.3. Mobile computing 1.0.4. Ubiquitous, Smart rooms
	1.1. Input Technologies	1.1.0. Mouse, computer keyboard 1.1.1. MIDI 1.1.2. Mobiles 1.1.3. Tangibles and wearables 1.1.4. Video 1.1.5. Audio 1.1.6. Electric instruments
	1.2. System Outputs	1.2.0. Audio 1.2.1. Visual 1.2.2. Video 1.2.3. Haptic 1.2.4. Raw data
2. Musical	2.0. Activities	2.0.0. Creating 2.0.1. Performing 2.0.2. Responding
3. Pedagogical	3.0. Learning Theories	3.0.0. Behaviorism 3.0.1. Cognitivism 3.0.2. Constructivism
	3.1. Users	3.1.0. Pre-school, primary 3.1.1. Secondary 3.1.2. Conservatory, University 3.1.3. Adults M and NM 3.1.4. Not defined
	3.2. Venues	3.2.0. Classroom 3.2.1. Lab 3.2.2. Everywhere 3.2.3. Web

0.2. Date—This dimension takes into account the year of publication. Only publications issued after 2000 have been included in the database.

4.2 The Technological Domain

The dimensions of the Technological domain refer to implementation aspects and technical requirements (in terms of hardware, interfaces, sensors) of a specific contribution or application. It can be argued that, from the user's perspective, it is important to know the domain in which the application is deployed (desktop environments, etc.), as well as the input-output devices enabling the interaction. In their taxonomy of user gestures in human-computer interaction, Karam and Schraefel (2005) propose a classification based on 4 categories: application domains, enabling technologies, system response, and gesture styles. This framework allows for a clear definition of the kind of application, the technologies employed for data input, and the system output modalities. The three technological dimensions in Table 4.1 bear a close resemblance to the categories of Karam and Schraefel (2005), although the corresponding nodes defined at the lower level are different as they have been chosen to be representative of the characteristics of digital materials for music education. The fourth category ("Gesture styles") included in Karam's taxonomy is very specific to the particular focus of their work (the use of gestures as a human-computer interaction technique) and, therefore, has no counterpart in the present proposal.

The Technological domain then includes the following dimensions and nodes:

1.0. Applications—This dimension refers to the kind of digital artifact employed in the learning activity, i.e., the object of the action. The nodes of this dimension are:

   1.0.0. Desktop—This is an umbrella term that includes all software running on a personal computer, including music sequencers, DAWs, and audio editors (Walzer, 2016), tutoring systems and games (Phon-Amnuaisuk and Siong, 2008), and programming environments (Hu et al., 2022; Petrie, 2022; Brown and Ruthmann, 2020);

   1.0.1. Virtual Reality (VR), Augmented Reality (AR)—These applications provide a real or simulated environment in which a perceiver experiences telepresence as in the case of VR, or superimpose virtual objects in a real environment, as for AR (Shen and Shirmohammadi, 2008). Typical examples of AR in music education are the systems for learning how to play instruments through information projected on the piano keyboard or the guitar fretboard (Rogers et al., 2014; Löchtefeld et al., 2011). Applications of VR can be found in the recreation of interactive environments for the study of the history of music (Gaugne et al., 2018) or for enhancing music listening abilities (Degli Innocenti et al., 2019);

   1.0.2. Tangible computing—These applications include systems capable of receiving and processing data coming from the manipulation of physical objects or from wearable and touch sensors. A well-known system is the *Reactable*, which can be used both for music creation and education (Franceschini, 2010; Xambó et al., 2013), while a recent device based on tangibles is Kibo (Amico and Ludovico, 2020);

1.0.3. Mobile computing—This node covers applications designed for tablets and smartphones. These allow for learning beyond traditional temporal and spatial constraints. Examples are *Paynter*, a software application for collaborative mobile music making (Hart and Williams, 2021) and an app for learning to play the guitar by ear (Caruso. et al., 2019);

1.0.4. Ubiquitous, Smart rooms—These are large-scale interactive environments that respond to user movements or gestures. The *Child Orchestra* (Core et al., 2017a) and *Robinflock* (Masu et al., 2017) for children's music creation are gameful examples of these applications. Interaction is based on body awareness, proprioception and kinesthesia (Jacob et al., 2008). The effects of bodily interaction and the possibility of sharing the learning experience with bystanders have not been deeply studied yet, and it is not clear how these factors influence the learning process (Johnson-Glenberg et al., 2009; Zanolla et al., 2013).

1.1. Input technologies—This dimension groups all the devices and technologies used to input data (audio, musical, performers' motion) into the system. The nodes in this dimension are:

1.1.0. Mouse and computer keyboard—These are the most traditional and widespread devices for interacting with the computer, also in the musical domain, for the manipulation of graphical elements in music production environments such as DAWs and sequencers, for quick note and duration input in score editors, and for interacting with elements in gameful environments (Mandanici et al., 2019);

1.1.1. MIDI—This is also widely used to let a wide variety of electronic musical instruments, computers, and other audio devices exchange data. In an educational context, the data produced by MIDI devices (mainly controllers such as electronic keyboards and pads) can be used to feed music notation software, sequencers (Schroth et al., 2009), and tutoring systems for computer-assisted music performance (Hackl and Anthes, 2017);

1.1.2. Mobiles—Tablets and smartphones are used as wireless input devices for music education software in a variety of ways. They can act as distributed controllers of the audio events, as in the *Soundcool* project (Berbel-Gómez et al., 2017); or can provide a surface for percussive performance, as in the *Rhythm Workers* application (Bégel et al., 2018). They can be used as image-based input tools for AR music education applications (Tan and Lim, 2019), or simply as sound recorders (De Lima et al., 2012);

1.1.3. Tangibles, wearables—Musical interaction with physical objects may happen through their creative arrangement on a customized board (Miotti et al., 2022) or by manipulating their surface (Amico et al., 2020). Wearables can be used to detect the motions of a violin player as in *MusicJacket* (Van Der Linden et al., 2011) or to act as markers for a computer vision system devoted to pitch, rhythm, and timbre detection (Farinazzo Martins et al., 2015);

1.1.4. Video—Cameras provide live video and motion data for a music performance. Live videos can be used to realize videoconferencing events for instrumental music teaching (Redman, 2020). The motion data of a live performance can be recorded by a camera and used to harmonize a melody or to improvise chord progressions (Mandanici et al., 2016);

1.1.5. Audio—Microphones are used for delivering audio signals to the computer for digital recording or DSP processing. Very often, they are employed in conjunction with MIDI instruments, e.g. to provide music data for DAWs and sequencers. They can also act as input devices for rhythm training (Alben et al., 2021) or singing voice assessment (Tardón et al., 2018);

1.1.6. Electric instruments—Electronic instruments can act as direct audio input devices for computer-based systems, e.g., applications for the automatic assessment of musical expression (Karlsson et al., 2009).

1.2. System Outputs—This dimension refers to the kind of outputs produced by a wide range of musical applications. The nodes in this dimension are:

1.2.0. Audio—Audio can be the product of an audio and video recording, the result of the combination of MIDI data and DSP processing, as in DAWs and sequencers, or the output of a program or patch (e.g., written in *Csound* or *MAX*). It can also be used in web-based environments for signal processing (Bareggi and Sargenti, 2021) or to provide sonic feedback for the detection of given performance features, e.g., the correct violin bowing, as in the 3D Augmented Mirror application (Ng et al., 2007);

1.2.1. Visual—Visual output is very common in AR tutoring systems or games for learning an instrument, chiefly the piano (Fernandez et al., 2016; Micheloni et al., 2019). It can be used as feedback on the acoustic qualities of a vocal performance (Welch et al., 2004) or for the visualization of string players' tuning skills (Hopkins, 2014);

1.2.2. Video—A live video output may be used as direct feedback for the assessment of an instrumental or vocal performance (Yin et al., 2005);

1.2.3. Haptic—Haptic output is delivered through appropriate actuators (vibrotactile, force-feedback, etc.). As an example, in *MusicJacket* (Van Der Linden et al., 2011) a vibrotactile system is mounted on the violinist's arms to indicate how to hold the instrument and how to bow in the correct way;

1.2.4. Raw data—These are output data that remain inside the application or system, awaiting further processing. This is the case of the rhythm teaching application described by Chou and Chu (2017) where data produced by tapping on a tablet are sent to a robot performance system.

4.3 The Musical Domain

Bauer's taxonomy as represented in Table 3.3 offers a detailed and comprehensive view of the activity types that can compose a music curriculum. For this reason, the artistic processes at the origin of Bauer's taxonomy will be used as the main reference for classifying musical activities enabled by technology.

The Musical domain include the following dimension and nodes:

2.0. Activities—This dimension contains the nodes corresponding to the three artistic processes defined in Table 3.1:

   2.0.0. Creating—This node groups together activities that range from traditional music composition to improvisation and music programming. A musical composition may be practiced by combining pre-recorded fragments (loops) on a collaborative DAW (Baratè et al., 2022) while music improvisation may be practiced through AR projections for learning piano blues and rock styles (Das et al., 2017). Creative music programming can also be taught from the very early years by employing playful environments, as in the *Multimodal LEGO®* (Baratè et al., 2017; Ludovico et al., 2017), or by applying a constructionist approach in learning music notation and composition (Repenning et al., 2020);

   2.0.1. Performing—This node groups the applications that help students in learning instrumental techniques (Ho et al., 2015), singing (Pérez-Gil et al., 2016), and conducting (Hollinger and Sullivan, 2007; Lee et al., 2004). There are also applications for learning to play the correct notes (such as the *Songs2See* game (Dittmar et al., 2012)), rhythms (Bégel et al., 2018), and more complex aspects of music theory such as harmony (*Song Walker* (Bouwer et al., 2013)). Other performing activities not necessarily connected to traditional instruments (live electronics, etc.) may also be categorized in this node.

   2.0.2. Responding—The activities belonging to this artistic process have been defined by Bauer as *"Listening and Describing"*, *"Analyzing"* and *"Evaluating"* (see Table 3.3), while the NCCAS defines them as *"Understanding and evaluating how the arts convey meaning"* (see Table 3.1). This node brings together applications that encompass both definitions, with the first one including a wider range of activities. Understanding and evaluating music includes knowledge of not only music theory and aural skills but also music history and culture. Bauer (2014) devotes a specific section to world music, emphasizing that little widespread attention has been given in the past to the study of non-western music in music education curricula, and proposing that a "strategy for engaging students in learning about world music is to have them assume the role of an ethnomusicologist". One application dedicated to the history of music is the *Evoluson* project (Gaugne et al., 2018). Other applications include ear training (Portowitz et al., 2014), music perception (Farinazzo Martins et al., 2015) or, in general, music education (Frosini et al., 2008).

4.4 The Pedagogical Domain

The Pedagogical domain deals with the pedagogical aspects related to the design of the applications. Specifically, the first dimension gathers nodes related to the three main learning theories reported in Chap. 2, the second considers the different types of recipients of the applications, while the third one takes into account a variety of venues where music education may occur, as a consequence of the growth of mobiles, motion-tracking devices, and connectivity.

In detail, the Pedagogical domain includes the following dimensions and nodes:

3.0. Learning theories—This dimension connects the application's design to the salient features of the three main learning theories. Clearly, this approach cannot take into account the complexity of theories and related educational practices. On the other hand, the purpose of this classification is to relate musical activities made possible by a specific application to these learning theories.

- 3.0.0. Behaviorism—All applications where knowledge is organized in sequential units and where a response from the learner is required and evaluated may be considered to be based on the principles of behaviorism. Examples of computer-assisted instruction can be found in drill-and-practice applications for the development of rhythm and sight-reading skills (Smith, 2009) and ear training (Loh, 2004);
- 3.0.1. Cognitivism—Applications that employ visual representations, multimedia displays, and tutoring functions fit perfectly this kind of approach. A number of tutoring systems exist for the study of instrumental techniques and music theory. An example is the *Music Paint Machine* (Nijs et al., 2012), which creates a digital painting of the movements of a clarinet player. Children exploit this visual representation to develop better performance practices;
- 3.0.2. Constructivism—Computer environments that encourage curiosity and the search for original and non-predetermined solutions provide fitting examples for this kind of learning approach. Pachet's *Continuator* (Addessi and Pachet, 2005) is a good example of an intelligent environment that stimulates children's creativity by responding to their musical input.

3.1. Users—This dimension concerns the end users of the application. The corresponding nodes are:

- 3.1.0. Pre-school, primary—Examples of contributions in this node include *JamMo*, a singing and composition game, which allows the user to select among a variety of musical patterns visually represented by musical instruments (Charissi and Rinta, 2014). In the *ImproviSchool* environment, a set of tangible music interfaces is used to compose a soundtrack for a fairy tale (Palaigeorgiou and Pouloulis, 2018). Music games are also particularly interesting in preschool and primary education. Applications such as *SAMI* (a set of 4 games aimed at children's ear training (McDowall, 2003)) engage children in fun musical activities, while large-scale interactive environments such as the *Child Orchestra* (Core et al., 2017b) involve full-body interaction in music production;

3.1.1. Secondary—For this category of end users, applications have a higher degree of complexity; as an example, applications for music production are more similar to professional sequencers and DAWs (Mellor, 2008). Moreover, here are distributed systems for the development of collaborative sound creations (Berbel-Gómez et al., 2017), pads for developing computational thinking (Gorson et al., 2017), as well as a web platform for the study of tonal harmony (Guichaoua et al., 2021);

3.1.2. Conservatory, university—Creating activities involve mainly computer programming software aimed at developing computational thinking abilities (Hancock, 2014; Moore, 2014; Siva et al., 2018; Mandanici and Spagnol, 2023). Performing activities aim at improving instrumental techniques through internet-based videoconferencing (Redman, 2020) or focusing on particular aspects of musical performance (e.g., the vibrato technique (Ho et al., 2015) or string instruments intonation (Hopkins, 2014)).

3.1.3. Adults M and NM—Applications in this node have been tested with adults, both musicians, and non-musicians, or are generally intended for adult users.

3.1.4. Not defined This is the default node for contributions containing no indication about intended users.

3.2. Venues—This dimension takes into account the different locations where music education activities may occur:

3.2.0. Classroom—This term indicates a school room adapted to fit the needs of music activities, e.g. ensemble performances, full-body movements, and class lessons. Technological music activities can be carried out at individual locations equipped with personal computers, digital instruments, and headphones. Microphones, loudspeakers, wall projectors, and web services complement the typical music-classroom input/output technologies;

3.2.1. Lab—All the applications that are meant to be used in an environment equipped with more specialized technologies than the classroom are labeled in this node. For example, cameras, sensors, tangibles, and actuators may be more typically found in the Lab;

3.2.2. Everywhere—This node embraces applications that run on mobile devices such as tablets and smartphones. They can be used as independent devices or linked to a local web for remote control of music events, as in the *Soundcool* project (Mateo et al., 2018);

3.2.3. Web—The web is a virtual venue for applications where distributed users employ shared working spaces and participate in collaborative activities. These are mainly creating activities, but there are also examples of performing activities such as *JamMo* (Paananen and Myllykoski, 2009).

4.5 Summary

In this chapter, we introduced the *Taxonomy of Digital Music Learning Resources (TDMLR)* as a tool for organizing the complex field of available applications for music education. According to the TPACK paradigm, the TDMLR is subdivided into 4 domains: Metadata, Technological, Musical, and Pedagogical. Each domain includes dimensions and nodes to define the application as precisely as possible. Application examples have been provided for each node.

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Chapter 5
Deploying the Taxonomy for Researchers and Educators

Abstract In this chapter, we propose a concrete application of the TDMLR, described in Chap. 4. We present an extensive database of publications on digital materials aimed at music education, as well as a web platform that we have designed, implemented, and publicly released, that allows users to explore and navigate the publication database through the dimensions and nodes of the TDMLR. Additionally, the web platform is equipped with analytical tools to make inferences about the most relevant principles and trends in available educational resources, along dimensions. Finally, we propose possible relevant uses of the TDMLR, based on the publication database and on the web platform.

5.1 A Database of Research in Digital Music Education

The TDMLR should be not only a theoretical instrument but also a practical tool that lets educators identify the most suitable approaches and products described in the scientific literature according to their needs.

To this end, extensive research was conducted in order to build a database of publications on digital materials aimed at music education. The choice to focus exclusively on scientific publications (journal articles, conference proceedings, books, book chapters, and, only exceptionally, master's or doctoral theses) was dictated by the need to obtain the most reliable information on digital materials, the use they are intended for, and the educational experiences connected to them.

This approach, while providing information about end users and sometimes about application assessment in teaching contexts, excludes two important categories of materials. The first one embraces the many undocumented websites that offer services, software, games, applications, and platforms for music education for both computer and mobile devices; the second category includes commercial applications or services. Both these categories are difficult to study for several reasons. Web sites are designed for the most varied purposes, ranging from music resource

M. Mandanici et al., *Digital Music Learning Resources*,
SpringerBriefs in Education,
https://doi.org/10.1007/978-981-99-4206-0_5

repositories (e.g. *BBC*[1]) to ear training and music theory applications (e.g. *Functional Ear Trainer*[2] *Musictheory.net*[3]) and instrumental practice (e.g. *gStrings*, *Piano Technicians Guild*[4]). Although some of them have a clear connection to educational practices and actually constitute valid teaching and learning resources, the lack of documentation can make their categorization questionable or undetermined. Moreover, commercial applications use proprietary software whose characteristics are not made public; usability data that would be needed for evaluating the applications are not easily accessible either. All these aspects would require adapting the analytical approach. For this reason, a thorough analysis of undocumented online resources and commercial applications is left for future work.

The building of the database went through different phases. The first phase involved searching using generic keywords such as “music learning applications”, “music education technology”, and “computer-aided music education”. This was carried out through both popular search engines on the web and databases dedicated to academic literature, including Google Scholar,[5] CiteseerX,[6] the ACM Digital Library,[7] the IEEE Xplore Digital Library,[8] JSTOR,[9] and Scopus.[10] After the collection of the first batch of papers, a bibliography-based search was carried out. At this point, a list of the main journals devoted to digital materials for music education emerged. Archives of specific journals, including the British Journal of Educational Technology,[11] the British Journal of Music Education,[12] Computers & Education,[13] the International Journal of Educational Research,[14] the Journal of Music, Technology and Education,[15] and Music Education Research,[16] were also examined.

All the collected publications were manually annotated with the nodes of the TDMLR. For some works, this operation was straightforward, since the authors provided clear indications about domains, dimensions, and nodes, while, in other cases, tags had to be inferred.

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[1] https://sound-effects.bbcrewind.co.uk/.

[2] https://www.miles.be/.

[3] https://www.musictheory.net/.

[4] https://www.ptg.org/home.

[5] https://scholar.google.com/.

[6] https://citeseerx.ist.psu.edu/.

[7] https://dlnext.acm.org/.

[8] https://ieeexplore.ieee.org/.

[9] https://www.jstor.org/.

[10] https://www.scopus.com/.

[11] https://onlinelibrary.wiley.com/journal/14678535.

[12] https://www.cambridge.org/core/journals/british-journal-of-music-education.

[13] https://www.journals.elsevier.com/computers-and-education/.

[14] https://www.journals.elsevier.com/international-journal-of-educational-research/.

[15] https://www.ingentaconnect.com/content/intellect/jmte.

[16] https://www.tandfonline.com/toc/cmue20/current.

In general, as already mentioned in Chap. 4, annotating publications was an iterative process that led to a partial redefinition and extension of dimensions and nodes, and a further re-annotation based on the occurred changes. Finally, once a stable version was reached, a further search on search engines and journal archives was conducted employing the keywords of the nodes.

All the selected publications were uploaded to *Zotero*,[17] a web-accessible reference manager designed to store, manage, and cite bibliographic entries. Exclusion criteria were applied to the retrieved academic papers. Contributions reporting music applications not explicitly aimed at education were discarded, as well as non-English papers. A temporal filter was also applied to exclude obsolete systems and applications. Thus, only papers written after the year 2000 were kept.

This database is intended to be a work in progress since the list of available resources as well as the scientific production addressing them are expected to continuously grow in time. For the sake of clarity, the list of collected publications does not claim to cover exhaustively the scientific production. At the time of writing this book, the collection amounts to a total of 144 entries.

5.2 A Web Tool to Explore the Taxonomy

In order to make the TDMLR accessible to Internet users and easily browsable, a web interface was developed and released as a public portal. Such a portal is available at http://techmusicedu.lim.di.unimi.it/. The underlying database is automatically fed by retrieving the papers and their tags from *Zotero*. From a technical point of view, the database is a dump in XML format.

5.2.1 Exploring the Taxonomy

In this section, the different ways offered by the Web interface to explore the TDMLR will be described. For future reference, the homepage of the portal is shown in Fig. 5.1.

The first available type of exploration is a hierarchical one, visible in the upper part of the interface. The navigation starts from the top level (domain), crosses the second level (dimension), goes down the third level (node), and finally brings to the scientific works belonging to the same node. For the sake of brevity, Fig. 5.1 shows the first two levels of the tree only.

This kind of exploration is very clear in presenting the structure of the TDMLR but is not particularly informative. As an example, products spanning across multiple nodes are not aggregated nor highlighted in any way; only by opening the information page of a given work, the full list of tags can be retrieved, possibly showing multiple values for a given hierarchical level. As an example, this is the case of Franceschini

[17] https://www.zotero.org/.

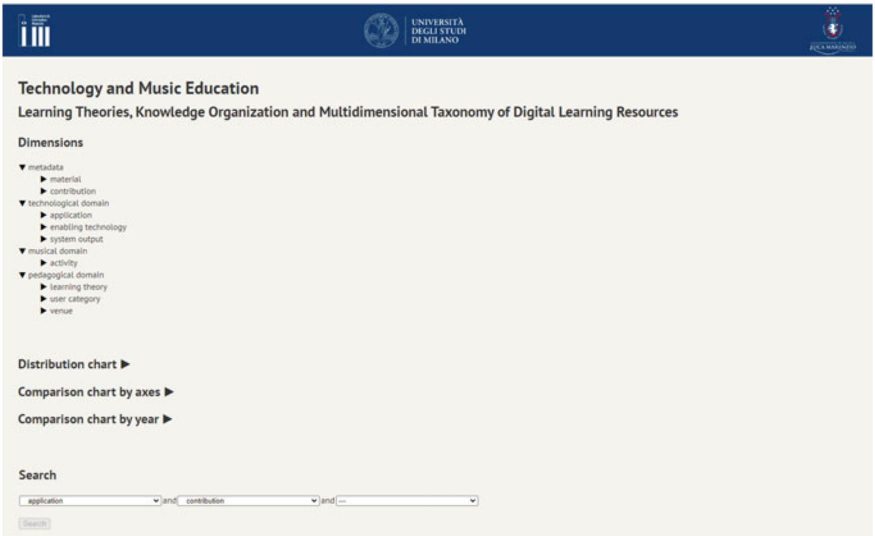


Fig. 5.1 The homepage of the portal

(2010),[18] that presents, in addition to many other tags, two different nodes (Audio and Visual) for the same domain (Technological) and dimension (System Outputs). Moreover, this kind of exploration does not allow querying the database by combining conditions (e.g., what papers simultaneously belong to both the *A* and the *B* node of the hierarchy).

Starting from this remark, the lower part of the interface presents a search tool explicitly conceived to combine up to three conditions in AND. The selection:

- can investigate a single property, at any level of the hierarchy. For example, a query by Cognitivism (node) would extract all papers dealing with such a Learning Theory (dimension) in the Pedagogical domain. In this case, the search tool merely provides a quick and alternative way to navigate the tree;
- can focus on many children of the same parent, i.e. siblings. For instance, a query by Web and Classroom would return all the papers describing educational activities taking place in both environments;
- can involve multiple children that are not siblings, also at different levels of the hierarchy. For example, a query by MIDI, Performing, and Pre-school, primary would select all the papers using MIDI (node) among all the available Input technologies (dimension) concerning the Technological domain, aiming at Performing (node) as an Activity (dimension) for the Musical domain, and addressing Pre-school, primary school students (node) as the target Users (dimension) in the Pedagogical domain.

[18] http://techmusicedu.lim.di.unimi.it/paper.php?id_paper=3Q7GQS6F.

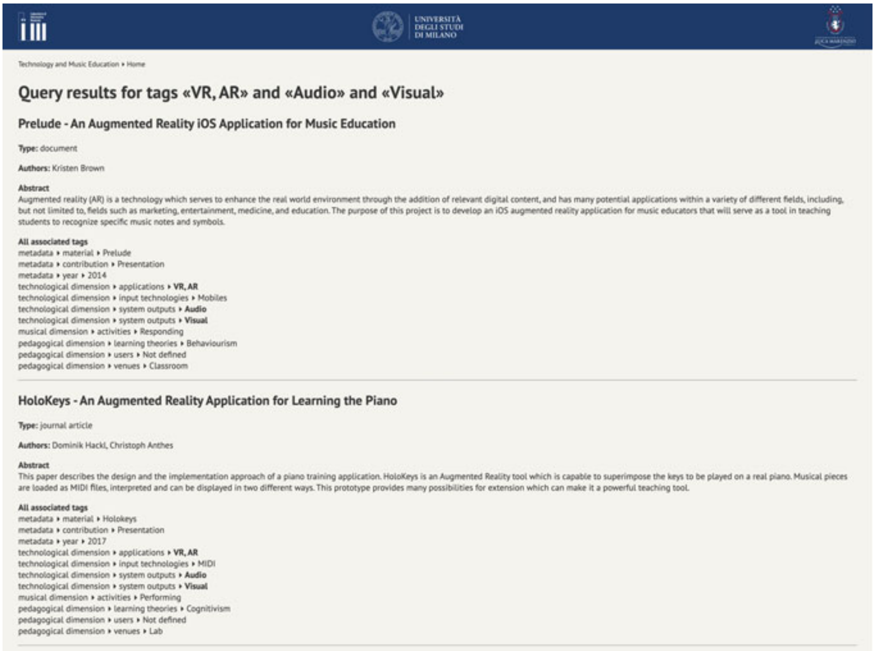


Fig. 5.2 Partial results of a query entered through the search tool

Such a way to explore the database provides educators with a more effective tool to find the applications and approaches that best suit their needs. Figure 5.2 shows the results of a query that combines 3 conditions in AND: (Technological domain ▶ Applications ▶ VR, AR) AND (Technological domain ▶ System Outputs ▶ Audio) AND (Technological domain ▶ System Outputs ▶ Visual). At the time of writing this book, such a query returns 7 results.

At the end of the navigation, conducted through either the former (hierarchical) or the latter (search) method, the platform returns a list of results, namely the scientific works responding to the navigation criteria. Each result can be clicked to open a short report that contains the title, the list of authors, the abstract, an URL to read the paper (only in the case of open access), and the list of tags in the TDMLR.

5.2.2 Charts

In addition to the navigation tool described in Sect. 5.2.1, the web interface offers visual aids to easily retrieve aggregated data about the publication database. Specifically, three charts are available at the time of writing: a distribution chart, a comparison chart by axes, and a comparison chart by year. The first chart shows the distribution of papers in a given dimension, which is the second level of the hierar-

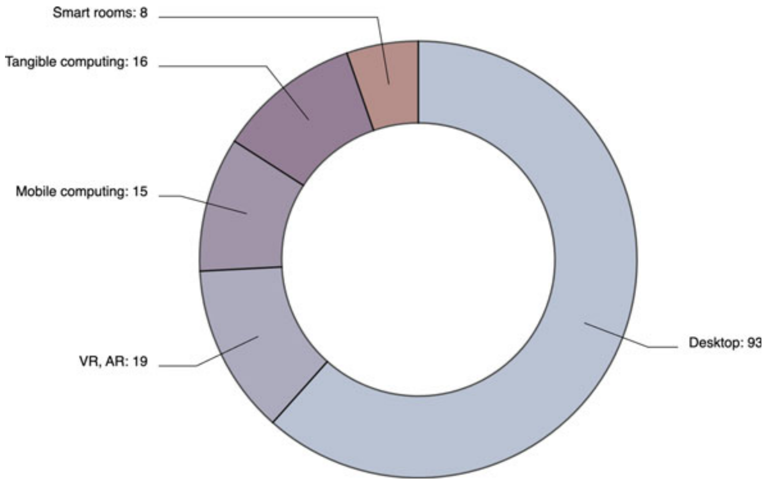


Fig. 5.3 Distribution chart for Technological domain ▶ Applications

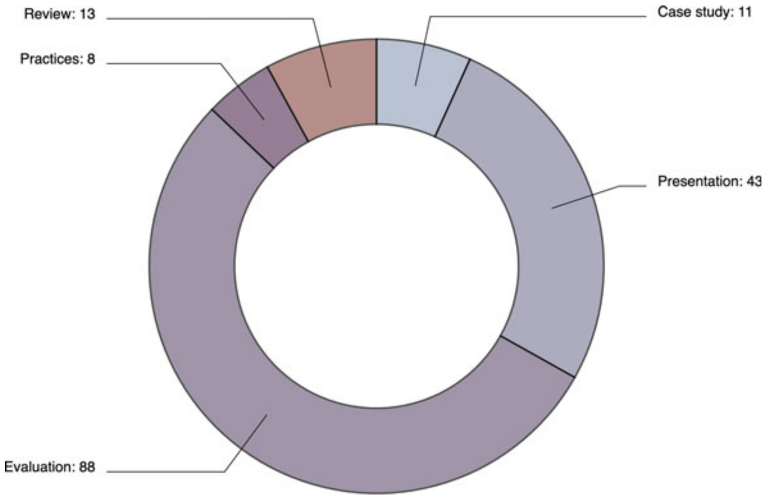


Fig. 5.4 Distribution chart for Metadata ▶ Contribution

chy. As an example, it is possible to explore the node distribution for Technological domain ▶ Applications (Fig. 5.3) or Metadata ▶ Contribution (Fig. 5.4). Sometimes, the distribution chart contains too many nodes to be easily readable, as in the case of Metadata ▶ Material, which is a list of all the products mentioned in the different papers; as the reader can easily guess, most of the cardinalities associated with nodes are set to 1.

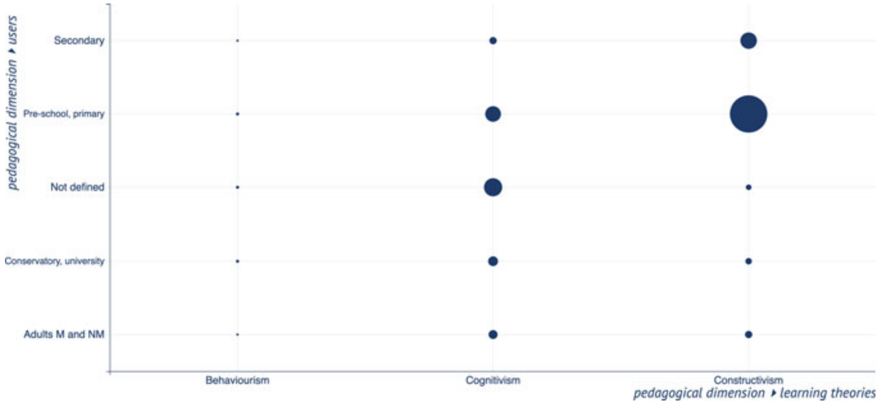


Fig. 5.5 Comparison chart by two dimensions (Pedagogical domain ▶ Learning Theories and Pedagogical domain ▶ Users)

The distribution along the Contribution dimension in Fig. 5.4 shows that more than half of the collected publications and applications are tagged with the Evaluation node, followed by the Presentation node.

The items belonging to the Evaluation node are likely to have a higher degree of reliability or maturity with respect to those belonging to the Presentation node since the applications here employed have undergone at least some form of testing. The items belonging to the Practices node also provide interesting insights, as these are the applications that have attracted the attention of teachers and have been used in the context of real classes: our data shows that these applications are a very small subset of the surveyed literature.

Another useful form of data visualization is the distribution of publication along nodes across two dimensions. The user can select the dimensions to investigate by picking them from the full list. As an example, the choice of Pedagogical domain ▶ Learning Theories and Pedagogical domain ▶ Users as the axes of the diagram unveils that most publications in the database currently focus on Constructivism in pre-school and primary school, whereas this learning theory is rarely applied in the context of higher education. This scenario is shown in Fig. 5.5.

Finally, the comparison by year lets the user select only one dimension and aims at providing the temporal evolution of node cardinalities for that dimension. On one side, the plot shows with clarity the evolution of all the nodes relating to a given dimension, but, on the other side, the interpretation of these figures must necessarily take into account the approach followed in annotating the database. As an example, Fig. 5.6 reports the aggregated results for Technological domain ▶ Applications. This seems to suggest that AR/VR applications started to be widely explored in 2011, which is plausible, while desktop applications fluctuated across years, which is arguable and should be better investigated: in particular, it must be remarked that the chart shows the number of publications in the database dealing with this kind of applications, rather than the number of applications themselves.

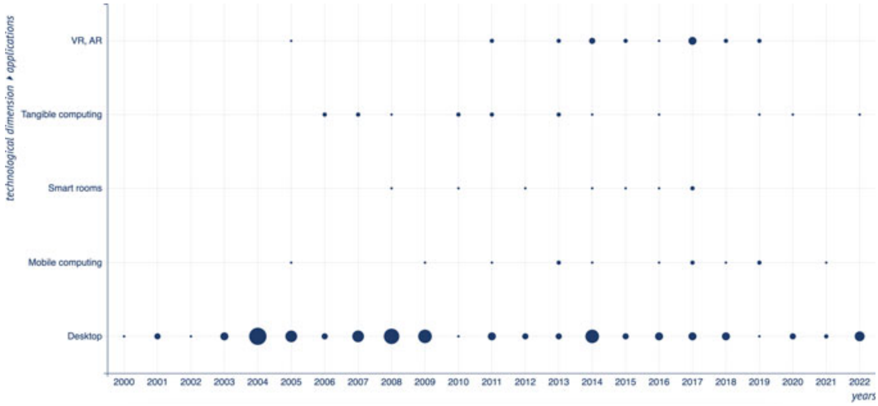


Fig. 5.6 Comparison chart by year for one dimension (Technological domain ▶ Applications)

5.3 Functions and Uses of the Taxonomy

According to Lambe (2014), public negotiated taxonomies are built with the aim of fostering common knowledge exchanges and can function as a standard for communication. This means to make explicit already existing shared concepts, structure them, and make them a matter of discussion. For a taxonomy to become socially negotiated, it has to undergo a process of investigation, discussion, testing, and revision. Currently, the tagging process that has generated the TDMLR has been a subjective one, based on several frameworks previously proposed in the scientific literature in the field (see Sects. 4.2, 4.3 and 4.4). In the future, the process should entail a debate among a community of stakeholders, who can discuss the single tags, approve or disapprove them, and change/update them upon majority agreement. Finally, taxonomies can contribute to item findability, content management, and knowledge management. In Sects. 5.3.1 and 5.3.2 some examples of how the TDMLR can be used in these categories are discussed.

5.3.1 The Taxonomy for Researchers and Designers

As shown in Fig. 5.7, starting from the 2000s until 2014 there has been a growing trend of interest in academic research toward music education applications. Also, according to Fig. 5.8 showing the distribution of publications along the Contribution (type) dimension, a large part of the collected items (namely, those in the node Evaluation) contain some form of assessment related to the use of the proposed application. Further analysis of the items belonging to the Evaluation node reveals at least three different assessment purposes:

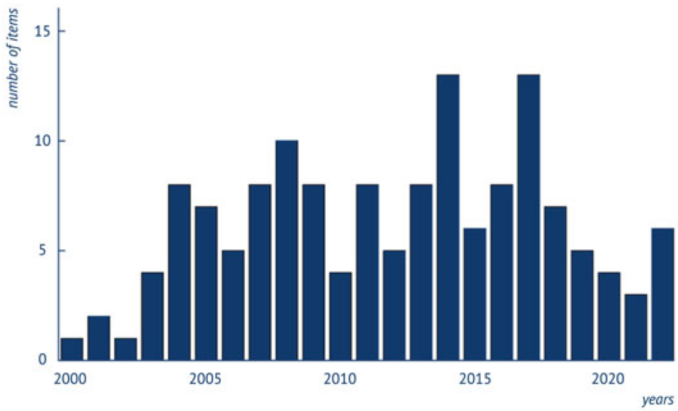
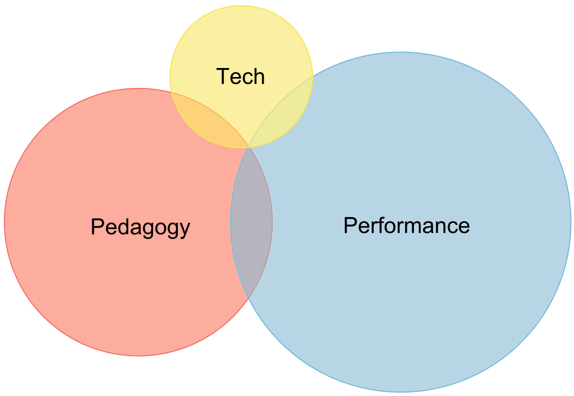


Fig. 5.7 Distribution of research articles by year

Fig. 5.8 Venn diagram of the research articles belonging to the Evaluation node, subdivided according to evaluation purposes



1. **Technology**. Here the focus of the assessment is only on the response of the system and on the reliability of its functioning.
2. **Performance**. For the applications described in this group, the main focus of the authors is on measuring how users can accomplish the tasks assigned during experiments, lessons, or workshops. Some studies also address the usability of the application: learnability, efficiency, memorability, errors, and user satisfaction (Nielsen, 1994).
3. **Pedagogy**. The authors of this group of publications focus on particular aspects of the learning process fostered by the use of music education applications such as interest, engagement, creative behavior, inclusion, and social interactions. Results are collected through questionnaires and direct observations, and additionally through the analysis of videos and other data produced by participants (e.g. drawings) according to the techniques of thematic analysis (Williamon et al., 2021).

The majority of contributions in this group deal with applications aimed at preschool or primary students, a favorite category for pedagogical analysis.

The technical assessment of an application is undoubtedly the first condition for its use, but it does not necessarily imply its actual adoption in real-life pedagogical contexts. Conversely, the performance of a system, both in terms of effectiveness in improving users' achievements and in terms of usability, is a fundamental condition for learning. However, it does not explain the whole learning process and, mainly, does not frame the experience in the psychological and pedagogical domains that are necessary to understand the nature of the educational experience with technologies. On the other hand, the assessment of pedagogical aspects is mainly derived from observation and only seldom paired with quantitative methods. Moreover, the pedagogical aspects cannot be limited to preschool and primary school students but should be extended also to other categories of recipients.

This brief analysis hints at the limitations of recent and current research in the field, outlining an imbalance of the researchers' interest in favor of performance and to the detriment of pedagogy. The TDMLR can help researchers and designers to overcome this limitation, by contributing to item findability, content management, and knowledge management.

- *Item findability.* Researchers and designers can make queries in the Musical and Pedagogical domains to find examples of how applications have been categorized.
- *Content Management.* The analysis of the items in the Technological domain and related dimensions can provide an overview of the techniques employed in the field and inspire the design of new applications.
- *Knowledge Management.* Research and analysis of items belonging to the 3 main learning theories may help researchers to become more aware of the relationships between technological tools and learning processes, and to link pedagogical research to the design of applications from many points of view (e.g. human-computer interaction and task design).

5.3.2 The Taxonomy for Educators

In fulfilling its statutory purposes, the International Society for Technology in Education (ISTE)[19] prepared a series of standards for the various stakeholders of the educational process (students, teachers, administrators, and coaches). With particular regard to teachers, these standards view the 21st century educators as:

1. **Learners**, for continually improving their knowledge in the technological domain
2. **Leaders**, for inspiring their students in the use of technologies.

[19] https://www.iste.org/about/about-iste.

3. **Citizens**, for framing the use of technologies in educational contexts also in a broader social perspective.
4. **Collaborators**, for engaging colleagues in the sharing of experiences related to the use of technologies.
5. **Designers**, for using their creativity in planning educational actions inspired by technologies.
6. **Facilitators**, for supporting students in their technological achievements.
7. **Analysts**, for interpreting data and for adapting their behavior accordingly.

These goals may appear prohibitive to achieve, especially if compared to the actual current level of technological knowledge of teachers. The European Commission's 2nd Survey of Schools: ICT in Education (EU Commission, 2019) reports that more than 60% of European students are thought by teachers who are engaged in their professional development in ICT only on a voluntary basis and without any compulsory training. This research reveals that even when teachers are confident in the use of technology they tend to use it more as an external tool rather than a way to evolve their teaching (DeCoito and Richardson, 2018). Moreover, the use of technology by teachers appears to be biased by sex (male teachers are more positive than females) and level of competency (Hsu et al., 2008; Fong and Holland, 2011).

The TDMLR may help teachers in discovering the affordances of technology in the music education process, by contributing to item findability, content management, and knowledge management.

- *Item Findability.* Through browsing the publication database along dimensions and nodes, teachers may improve their role of **Learners** by obtaining an up-to-date overview of existing applications for music education according to artistic processes and learning theories.
- *Content Management.* The analysis of these items may inspire teachers as **Designers** in the building of didactic plans based on a better awareness of the psychological processes underlying the use of educational technologies. The spectrum of applications along the Venue dimension may enlarge the range of action of the educational process, facilitating the birth of new approaches and relationships among teachers, students, and peers.
- *Knowledge Management.* The disclosure of the technical aspects hidden behind the simple observation of a working application is an important aspect of technology integration. Knowledge about the application, input technologies, and system output dimensions may enhance the role of teachers as **Facilitators**, **Leaders**, and **Collaborators**, increasing their confidence in the technology.

5.3.3 Validation of the Taxonomy

In this book, we present TDLMR as the result of collaborative work within the restricted group of the authors, well aware that the next step must be a thorough validation of it. We envision at least two different verification domains:

1. A technical domain, where TDMLR can be verified according to the criteria of *completeness*, *precision*, and *timelessness* as defined by Mountrouidou et al. (2019);
2. A usability domain, where TDMLR can be verified according to the criteria of *clarity*, *understanding*, and *relevance*. This must undergo an evaluation process by designers, researchers, and educators.

As far as concerns the technical domain, *completeness* requires that the items responding to the characteristics enumerated in Sect. 5.1 are actually present in the TDLMR while respecting the exclusion criteria. *Precision* concerns the accuracy of the tagging process, i.e. if the item has been placed in the correct nodes of TDLMR. *Timelessness* aims at verifying if the domains, dimensions, and nodes are adequate or expandable in view of incoming and future new items.

The assessment for the usability domain could include *clarity* in the names and definition of domains, dimensions, and nodes; *understanding* e.g. of the results of a query; and *relevance* of the information obtained with respect to the user's sector (designer, researcher or educator). For each of these domains and criteria, customized assessment methods must be proposed, discussed, and tested. The assessment should involve not only the researchers' team but also other subjects such as the authors of the papers classified in the database, and music teachers.

The validation of TDMLR as hereby proposed is a complex work, which goes far beyond the scope of the present book. For this reason, we decided to defer it to a later publication.

5.4 Summary

In this chapter, we highlighted the potentialities of the TDMLR, not only as a theoretical framework for research in the field of digital music education but also as a practical tool designed to foster knowledge exchange between designers and educators. In particular, the TDMLR can contribute: to item findability, by using the web tools specially designed; to content management, by providing an overview related to the domain, dimension, or node used in the search; to knowledge management, by analyzing the data obtained from the TDMLR. Finally, we presented a hypothesis for future validation of the taxonomy.

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Chapter 6
From Research to Educational Practice

Abstract This final chapter addresses the connections between academic research on technology-assisted learning and the actual educational practice in the classroom. First, the chapter analyzes the main causes hindering a productive dialogue between teachers and researchers, which may be attributed to both parts. Then, some proposals are formulated to make such dialogue more effective and fruitful. These include approaches to improve the accessibility of research results to teachers, a stronger emphasis on open educational resources, and a focus on the sharing of users' data (both teachers and students) as a fundamental asset for improving digital learning applications.

6.1 Revitalizing Educational Practice

One of the aims of the TDMLR is to provide a theoretical tool that can contribute to linking research to educational practice. Many studies approached this problem from the point of view of the various stakeholders of the educational process (teachers, school leaders, intermediaries, and researchers (Vanderlinde and van Braak, 2010). The link between educational research and teachers' everyday practice is considered important for coping with actual problems in the teaching methods and for increasing theoretical knowledge about them (Reeves et al., 2011). Moreover, research can help in ensuring equity and quality in learning opportunities, a very important factor in contemporary society (Bransford et al., 2009). Yet, in spite of all these positive interconnections, the literature reports a very scarce and problematic interaction between the two (Kennedy, 1997; Burkhardt and Schoenfeld, 2003; Biesta, 2007).

In the specific case of music education, the benefits of technology are widely recognized (Akombo and Lewis, 2019; Dunn, 2014), but digital learning resources are still not making a significant impact in actual educational practices. The discussion around the TPACK framework in Sect. 3.1 has highlighted one possible cause, i.e. insufficient professional development offered to teachers to acquire the necessary technological knowledge and its intersections with pedagogical and content knowledge. However, other causes can be identified by hindering a productive dialogue

M. Mandanici et al., *Digital Music Learning Resources*,
SpringerBriefs in Education,
https://doi.org/10.1007/978-981-99-4206-0_6

between teachers and researchers. Particularly, Broekkamp and van Hout-Wolters (2007) considers four main points:

1. *Educational research produces few meaningful results.* This is due to many reasons, including the complexity of educational research, the lack of experimental validation, and the low technical quality of research methods. Kennedy (1997) also calls into question research design, whose goal is to outline the main variables of educational experiments and to indicate their causal relationships. Designing repeatable tests in controlled conditions aids the interpretation of experimental results and minimizes the risk of hidden variables: while this is relatively straightforward to achieve in the laboratory, only engaging with real classroom environments can produce useful knowledge (Brown, 1992).
2. *Educational research is far from practical application.* Research results are too limited, not immediately available, and expressed in a language that is not comprehensible to teachers (Gore and Gitlin, 2004). The lack of organized databases, as well as the scarcity of systematic reviews and documents for the summarization and explanation of results, make research a subject for academics and not accessible to teachers. Kennedy (1997) observes that the problem is not making research merely reachable by teachers as much as making it conceptually available for them, as the innovative power of research resides in its ability to foster a change in the teachers' way of thinking.
3. *Teachers do not believe that researchers really know what happens in the classroom.* As observed by Bransford et al. (1999), teachers generally are unwilling to seek help in deciding their educational approach. The focus of research is considered too abstract and narrow in scope to actually serve as an aid in real classroom contexts that are characterized by many students, different problems, and limited time to cope with them.
4. *Teachers do not make appropriate use of the findings of researchers.* If teachers do not consider educational research relevant, it is also very unlikely that they will use it (Burkhardt and Schoenfeld, 2003). Moreover, many teachers need support for approaching research and for evaluating it. In this respect, the figure of intermediaries—already studied for technology transfer and for promoting innovation in industrial contexts (Howells, 2006)—may be a useful reference example. Intermediaries could provide a link between teachers and researchers and help in disseminating knowledge and experience in the use of educational technologies for music teaching.

In a complementary fashion, Bransford et al. (1999) outline four ways through which the gap between research and educational practice may be reduced. These are depicted in Fig. 6.1. Firstly, Educational Materials (rephased as *Digital Materials* in the present context): teachers will not change their habits without the introduction of new tools, such as software, platforms, or applications. On the other side, those who design these tools must incorporate pedagogical principles to accommodate students' needs. Secondly, pre-service and in-service teachers' education—already discussed as determining factors in the process of technology integration—need the support of the third element, which is policy: policy-makers at both the national and the local

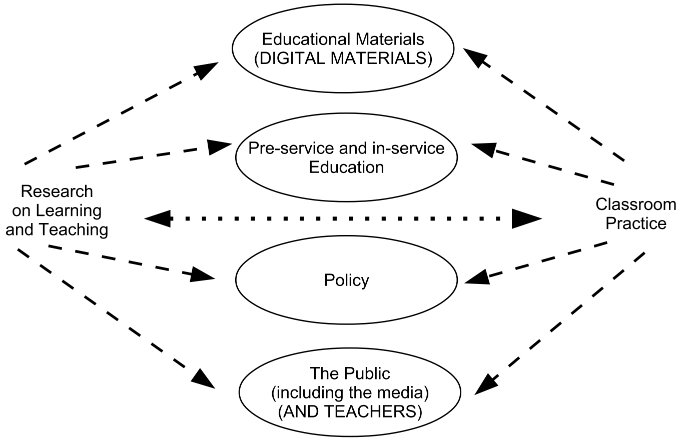

Fig. 6.1 Paths through which research influences practice. The capitalized items are adapted from Bransford et al. (1999)

levels must be aware of their responsibilities in fostering technological advances in schools and in providing an adequate cultural and economic reinforcement in this direction. Finally, the Public, which includes the media, parents, opinion makers, and—in addition to the original proposal by Bransford et al. (1999)—*teachers* themselves, whose contribution represents an unavoidable element. Contrary to what one may believe, even in public opinion there is no general consensus about technology integration in schools, and, above all, there is no awareness of what this can entail in adapting study programs (Delle Monache et al., 2021).

6.2 Providing Accessible Contents to Music Teachers

As discussed in Sect. 5.3, the TDMLR is a theoretical tool that can prove useful in many contexts, including the findability of ideas, resources, and approaches that can help music teachers in organizing their work in the classroom. On the other hand, the above-listed problems in the relationship between research and educational practice include the lack of a common language and of well-organized databases. In fact, a query in the publication database through the TDMLR website merely returns titles and types of contributions, author names, URLs, and abstracts (if available), along with associated tags. In order to make sense of this information, a music teacher should be able to:

1. search popular scientific databases (e.g. Google Scholar, Scopus, ERIC, IEEE Xplore, etc.) for retrieving publications;
2. read and understand manuscripts written in academic English;
3. analyze publication contents in order to link them to the associated tags.

Moreover, a publication itself is often not fully informative in many respects, e.g.:

- it does not always describe in a clear way the technical setup necessary for the application to run;
- usually it does not offer any information about where to find the executable and/or source code of the application (is it stored in some repository? Is it still running or does it need revisions?);
- it does not always provide a simple description of a scenario or possible pedagogical uses of the application.

In order to collect missing information and to make it more accessible to music teachers, this has to be retrieved from the original authors. Therefore, a questionnaire aimed at the researchers who designed and developed the applications was prepared. A mailing list collecting all the e-mail addresses of the researchers was obtained from publicly available information in the original publications. More precisely, the database was subdivided into two groups: publications that (i) present applications designed and developed by the authors, or (ii) describe uses of existing commercial or free applications (e.g. Pure Data, Cubase, GarageBand) not originally conceived for educational purposes. Only the first author of the papers belonging to the first group was invited to respond to the questionnaire, which was essentially aimed at:

- verifying the availability and effective usability of the application;
- collecting ready-to-use information about it (short description, scenarios of use, date of release);
- offering examples of pedagogical uses of the application.

The whole questionnaire with an overview of the responses and a list of videos is available in Appendix A. Out of the 93 e-mails sent, only 13 researchers responded to the questionnaire, a very low number that seems to support the idea that researchers are scarcely interested in the dissemination of their work to teachers and educators. This aspect has been stressed by Stevens (2004) who criticizes widespread negative habits in educational research: "Too often we write and do research for ourselves [...] Once research has been published in a prestigious academic journal we move on to the next study".

In this respect, Burkhardt and Schoenfeld (2003) suggest that a change in the academic reward system may help. Fostering creative research design and giving more credit to contributions aimed at improving practice can help to shift from smart but ineffective to impact-focused research.

However, one of the most relevant questions (Q9—"Can the application be used by a music teacher as it is?") obtained 9 positive and 4 negative answers. Q13—"Is there a repository where the executable of your application can be accessed?" obtained 8 positive, 4 negative, and 1 missing answer. Q15—"Can you provide pictures or videos of the application?" gave us 10 links with very useful material for understanding the utility of the application at a glance. The complete overview of the responses and a list of the videos provided by each respondent is reported in Appendix A.

6.3 Fostering Open Educational Resources

The results of the questionnaire discussed in the previous section suggest that the impact of TDMLR would be much greater if a much larger number of applications were actually available for educational use. This remark is mirrored in the philosophy of OER (Open Educational Resources), which "[…] are learning, teaching, and research materials in any format and medium that reside in the public domain or are under copyright that have been released under an open license, that permit no-cost access, re-use, re-purpose, adaptation and redistribution by others" (UNESCO, 2019).

OER can include open courseware, software tools, applications and learning management systems, e-learning materials, and communities, repositories of learning objects, journals or other materials, and free educational courses (Hylén, 2006).

Downes (2007) analyzed in depth several problems connected to OER by reflecting on funding models, technical models, and content. If OER must be free access for the community, the question of how this can happen without costs for the users becomes a major issue. OER's sustainability is not only connected to the costs for the production of content, but also to its management and—mainly—to the policy, economy, and objectives of the provider.

OER can be extremely beneficial to all the stakeholders of the educational process because—when used in combination with ICTs—they have a great potential in improving knowledge and quality of learning. According to Butcher (2015) OER can contribute to providing high-quality instructional material for fostering meaningful learning experiences; manipulation, adaptation, and modification of resources allow for the creation of new open educational materials in a context where students are the active makers of their own knowledge; OER can be a source of capacity building for teachers and policymakers in the effort to innovate educational design and practice.

OER's sustainability, content policy, and production are tightly related. Particularly, content production gives raise to the birth of pedagogical innovation and methods, as shown next in Sect. 6.3.1. The benefits of the application of OER pedagogy to music education and research are analyzed in Sect. 6.3.1.

6.3.1 OER-Enabled Pedagogy

Wiley and Hilton III (2018) define the concept of *OER-enabled pedagogy* as a set of educational practices based on the five properties of OERs, called the 5Rs. These refer in particular to:

1. *Retain*: the right to download, duplicate, and store the content;
2. *Reuse*: the right to use the content in various ways and contexts (presentations, lessons, videos, websites, etc.);
3. *Revise*: the right to modify and adapt the content according to the context;
4. *Remix*: the right to incorporate new materials in the original content;

5. *Redistribute*: the right to share copies of original as well as revised content.

OER-enabled pedagogy can be tested through four conditions, which in turn can be met only if the 5Rs properties are realized:

- students produce original artifacts (essays, poems, tutorials, videos, songs, compositions, graphics, code, etc.) or revise/remix existing material
- artifacts have a value beyond supporting the learning of its authors
- students share publicly their artifacts
- students release an open license of their artifacts.

OER-enabled pedagogy describes a constructionist view of teaching and learning with a focus on the production and sharing of artifacts. Some examples of related activities are the creation of tutorials and learning materials prepared by the students to help other students; the preparation of worked examples (step-by-step visualizations to drive the students to solve a problem); the creation of questions for testing other students' abilities (Jhangiani, 2017), and so on.

6.3.2 OERs in Music Education and Research

It is useful to analyze the 5Rs in the light of music education applications, which can be in general labeled as "software tools".

1. *Retain* assumes that the application is actually freely available, which requires to verify if the application:
   - is still working (i.e. it is not affected by changes in the operating system, or by other update issues—see Q8 of the questionnaire in Appendix A);
   - can be used by a teacher as it is or needs further adjustment (see Q9);
   - can be accessed through the executable or the source code (see Q13–14).
2. *Reuse* (or rather *Use*) can be documented through videos, reports, observation, and didactic projects elaborated and tested by teachers. For a music education application born and tested in a laboratory or in a very limited number of real contexts, the possibility of undergoing real class-life tests could be a very important result.
3. *Revise* may be interpreted as the possibility of applying iterative design, which is a collaborative process where developers adjust some features of the application according to the suggestions of the users (Baecker et al., 1995). Teachers and students could test the application and return their advice for improvement to the designers.
4. *Remix* may assume different forms:
   contributing new materials to a repository employed for educational music games, uploading one's work to a public repository of music compositions, making new versions of already existing patches for a music programming language, proposing a didactic project related to the use of an application in a customized repository, and so on.

5. *Redistribute* is realized by making music educational resources public through open repositories, archives, community websites, and social media.

Besides generating innovation in music pedagogy, the 5Rs may also be vital for supporting research. On the web, many platforms that offer high-quality paid services for learning music theory[1] or for playing a musical instrument[2] may be found. However, researchers will meet some difficulty to discover how these services actually perform. Also if an inquiry from the authors has not yet been addressed to the managers of these commercial enterprises, it is not unlikely that any information provided is biased by the corporate interest.

Freely available platforms may offer some more information. *Chrome Music Lab*[3] provides a relevant example, as it is built upon freely accessible web technology (Web Audio and Web MIDI APIs, Tone.js), it is open-source and released under a permissive license which allows modification, distribution, and even commercial use under specific conditions. The platform offers 14 experiments to help music education with playful experiences about rhythm, notes, harmony, sound physics, etc. Every experiment page is endowed with an explanatory section with the invitation to share requests, impressions, ways of using the experiments, etc. To this end, also a Twitter page[4] is available with many videos showing educational experiences with *Chrome Music Lab*. Thus, while points 1 and 2 of the 5Rs are fully satisfied by the availability of the platform across various devices and browsers, point 3 is potentially open to iterative design by the possibility offered to the teachers to interact with the designers. But the *revise* property is also satisfied for developers, who can access the code of the majority of the experiments and make their own changes. The *remix* and *redistribute* properties are realized through the sharing of educational experiences through Twitter. Although not fully developed—the experiences are expressed through videos and lack of analysis, commentary, and other pedagogical information—however they testify to the desire to collect information from users and share it with others.

6.4 Involving and Analyzing the Final Users

Strictly connected to OER is the issue of the availability of users' data for researchers. Open access to user data is a major issue in many research areas, including computer-assisted instruction (Harrer et al., 2009), and can be exploited to aid the understanding of the learning process as well as to offer additional support to the learners themselves (e.g., by taking into account individual profiles and cognitive processes and adapting the learning environment to their needs and preferences).

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[1] https://www.musictheory.net.

[2] https://yousician.com/.

[3] https://musiclab.chromeexperiments.com/.

[4] https://twitter.com/i/events/826075807915192320.

Users' data are the basis of interaction analysis, which is a set of methods for understanding the characteristics of communication, collaboration, and task completion in several computer-mediated settings (Harrer et al., 2009). These methods—generalized in the six phases of data capture, segmentation, preprocessing, qualitative and quantitative statistical analysis, visualization, and interpretation—can be employed to discover the frequency of use of the application, the rate of success of task completion, and any information that can be obtained from the tracking of the user's actions. The management of users' data implies many open issues such as ownership, accountability, data permission, anonymity, identity, and shared data policies (Evans, 2011; Al-Khouri et al., 2012), whose discussion—although fundamental for the advancement of music education research—cannot be discussed properly in this book. Rather, in order to exemplify how users' data collected in the classroom can be exploited in the development of a digital learning application, the remainder of this section analyzes a case study recently conducted by the present authors.

Harmonic Touch is a web platform that is based upon three experiences[5] for the knowledge and practice of tonal harmony (Avanzini et al., 2019). The platform tracks every action performed both by anonymous and registered users, allowing thus the realization of extensive interaction analysis to disclose important elements, i.e. if some search pattern emerges, what drives the user to select a particular chord sequence, how many trials the user needs to perform the task correctly, etc. The platform is still under development and awaits to be updated after experimental and users' advice. Early experimentation in the classroom was conducted in two elementary schools (Marini et al., 2022) and utilized the second experience, which is focused on the detection of harmonic rhythm. The user has to click on a series of subsequent points representing upcoming chords in a melodic excerpt being played back. For each game played, the system logs the user name, the song employed, the list of the timings of the clicked points, if the performance has been confirmed by the user, and finally if the game has been successful. A graphical representation of the user's performance is depicted in Fig. 6.2, where the correspondence of the blue dots (the clicked chord) with the vertical dashed line (the correct timing) shows immediately where the user is first or late in identifying the harmonic change.

In the following analysis, the potentialities of the platform will be analyzed in light of the 5Rs and users' data policy.

1. *Retain.* The web platform is freely available and works with every browser and various devices (computer, tablet, and mobile).
2. *(Re)Use.* The platform can be accessed in three ways: anonym user, registered teacher, and registered student. The user's identity is managed by the teachers' accounts, which control the associated students' accounts and can choose the set of materials (songs) to use in their experiences. Currently, registration to the platform can be completed only upon agreement with the authors. Self-registration, with information on personal data processing and consent by the user will be provided in future releases.

[5] https://harmonictouch.lim.di.unimi.it/.

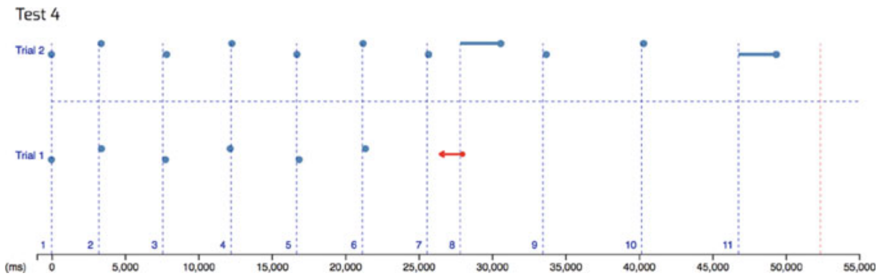

Fig. 6.2 Graphical representation of user's performance of Experience 2 of *Harmonic Touch*. The vertical dashed lines represent the right time when the new chord occurs. The blue dots and horizontal segments show if the chord has been clicked in time or late or in advance with respect to the dashed vertical line. The red line and arrow show a new trial starting for the same test

3. *Revise.* The first experimental phase produced several suggestions from teachers:

    a. provide the possibility of keeping track of successes and failures of students through the implementation of a board of scores, while currently the score is shown only game by game. This would be a very important tool for teachers to control students' progress, and for students to compare with their peers;
    b. more fine-grained forms of visualization of mistakes were devised to be made available to teachers (see Avanzini et al., 2021 for examples).

    From the analysis of the behavior of the students, many important suggestions for improving the educational approach were derived, such as:

    a. endow the platform with tutorials, videos, and animated examples related to the three experiences, to facilitate the understanding of what is required from the user;
    b. embed a blog in the platform for the sharing of experiences, as children who took part in the experimental activities showed a great interest in the completion of the tasks proposed by the platform and spontaneously tried to communicate their success with their peers through social media;

4. *Remix.* New materials can be incorporated into the platform: in particular, a useful form of contribution is adding new songs to the database already available. Every teacher needs to follow her/his personalized approach to education, and this can be obtained by following a didactic plan based on selected materials. On the other hand, children often asked to play with their favorite songs. Currently, the songs are processed and uploaded under agreement with the authors, but an automated supervised process could be implemented.
5. *Redistribute.* Videos, didactic plans, results, and visualizations of selected users' data could be made available on social media and linked from the platform.

This analysis allows discovering where the harmonic changes are more difficult to detect and why. This information, together with the musical characteristics of the musical excerpt (key, duration, regularity of the changes, number of chords involved) can deliver important knowledge about music perception and can help the teachers to organize didactic plans according to the difficulties of the students.

6.5 Summary

The conjunction between research and educational practice is a difficult task that must overcome many obstacles in order to succeed. The availability of digital materials ready for use in the classroom is one of these. We addressed this problem by analyzing one of the outcomes of TDMLR, i.e., scientific articles difficult to be used by educators. In order to collect missing information about the applications, we asked the authors to fill in a questionnaire with examples of their pedagogical use, but we obtained very few answers. We concluded this chapter and the whole book by outlining the potential of open resources and open data to enhance research and to make it closer to the needs of educators and students.

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Appendix A
The Questionnaire for Developers

The following Tables A.1, A.2, A.3 and A.4 summarize the questionnaire sent to researchers and the most relevant responses.

Table A.1 The 16 questions for developers

	Questions
Q1	E-mail
Q2	Name
Q3	Affiliation
Q4	What is your application's name?
Q5	Please write a short description of the application
Q6	Please describe one or more scenarios for the use of the application
Q7	What are the technological requirements for using your application? Please list devices, environment, constraints, etc.
Q8	Would you define it as a working application? If not, please explain why
Q9	Can the application be used by a music teacher as it is? *[Yes / No, it needs further development to be usable in a real context/No, it can no longer be used]*
Q10	As far as you know, has your application been employed in real class activities beyond the experimental setup? *[Yes / No / Maybe]*
Q11	When did you first release your application?
Q12	Did you ever release new versions? In this case, please provide details
Q13	Is there a repository where the executable of your application can be accessed? In this case, please provide the link
Q14	Is there a repository where the source code of your application can be accessed? In this case, please provide the link
Q15	Can you provide pictures or videos of the application? In this case, please give us the links
Q16	Can you list the publications where your application has been addressed?

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Table A.2 An overview of the answers to Question 9 (Q9)

Developer (Q2)	Application (Q4)	Usability (Q9)
Jesús Tejada	Cantus	Yes
Ronan Gaugne	Evoluson	Yes
V.J. Manzo	EAMIR	Yes
Carlos Torres	MMPiano AR	No, it needs …
Marcella Mandanici	Harmonic Walk	Yes
Valéria Farinazzo Martins	MusicAR	No, it needs …
Luca Andrea Ludovico	Music e-book	No, it needs …
Frederic Bevilacqua	Wireless sensor interface	Yes
Maria del Puerto	SAMI	Yes
David Howard	VOXed (originally WinSINGAD and SINGAD)	No, it needs …
George Tambouratzis	VEMUS	Yes
Marcella Mandanici et al.	Harmonic Touch	Yes
Alexander Repenning	AgentCubes	Yes

Table A.3 An overview of the answers to Questions 13 and 14 (Q13–14)

Developer (Q2)	Application (Q4)	Availability (Q13–14)
Jesús Tejada	Cantus	https://www.cantus.es
Ronan Gaugne	Evoluson	It is accessible from inside Inria, in the Inria gitlab. An external diffusion could be foreseen
V. J. Manzo	EAMIR	https://www.eamir.org
Carlos Torres	MMPiano AR	No
Marcella Mandanici	Harmonic Walk	No
Valéria Farinazzo Martins	MusicAR	No
Luca Andrea Ludovico	Music e-book	No
Frederic Bevilacqua	Wireless interface	https://ismm-apps.ircam.fr/como-vox
Maria del Puerto	SAMI	No
David Howard	VOXed	I do have it and it could be made available
George Tambouratzis	VEMUS	The executable of the application is available upon request
Marcella Mandanici et al.	Harmonic Touch	https://harmonictouch.lim.di.unimi.it
Alexander Repenning	AgentCubes	https://agentsheets.com

Table A.4 An overview of the answers to Question 15 (Q15)

Developer (Q2)	Application (Q4)	Video (Q15)
J. Tejada	Cantus	https://youtu.be/uTtEOqkVqBU
R. Gaugne	Evoluson	http://people.irisa.fr/Ronan.Gaugne/evoluson
V. J. Manzo	EAMIR	https://www.eamir.org
C. Torres	MMPiano AR	https://www.behance.net/gallery/50792835/MikuMikuPiano-AR
M. Mandanici	Harmonic Walk	https://youtu.be/c4ru468eqM0
V. Farinazzo Martins	MusicAR	*n.a.*
L.A. Ludovico	Music e-book	*n.a.*
F. Bevilacqua	Wireless interface	https://vox.radiofrance.fr/ressource/como-vox-lapplication-de-direction-de-choeur
M. del Puerto	SAMI	*n.a.*
D. Howard	VOXed	Pictures of screens are in: Howard, D.M., Brereton, J., Welch, G.F., Himonides, E., DeCosta, M., Williams, J., and Howard, A.W. (2007). Are Real-Time Displays of Benefit in the Singing Studio? An Exploratory Study, Journal of Voice, 21, (1), 20-34.
G. Tambouratzis	VEMUS	https://youtu.be/1zwVfSswb9Y
M. Mandanici et al.	Harmonic Touch	https://youtu.be/62FdoBUia-g
A. Repenning	AgentCubes	https://docs.google.com/presentation/d/1L-YfdE0UDxoi0kw_AyNvmoKVak9ZNKI03dTqYFMF2sM (contains slides with videos)

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