Computers in Music Education

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Abstract

This paper provides a survey of the applications of computers in music teaching. The systems are classified by musical activity rather than by technical approach. The instructional strategies involved and the type of knowledge represented are highlighted and areas for future research are identified.

1 Introduction

There have been numerous attempts to use computers in music education. As a result of the highly interdisciplinary nature of the field, these applications use different and sometimes contrasting approaches. This paper classifies applications by activities involved in musical teaching, and addresses the instructional strategies, if any, involved. The categories considered are computer applications intended to:

- teach fundamentals of music;
- teach musical performance skills;
- perform analysis of music;
- teach musical composition skills.

Applications in which the computer fulfils only an instrumental role such as sequencer and music notation packages will not be covered by this review; our focus is on applications in which the student is encouraged to freely explore educational environments and micro-worlds or is guided through an instructional task.

Music education applications use a range of techniques from Computer Assisted Instruction (CAI) to Intelligent Tutoring Systems (ITS) [1] in conjunction with different instructional strategies. Whilst this is a continuum, differences between these approaches at the extremes will be considered here. Contrasting with ITS, CAI systems present a limited teaching strategy, as they have no explicit representation of the knowledge to be taught or ability to reason about it, and cannot differentiate between different students. On the other hand, an ITS basically consists of an instructional environment containing three kinds of knowledge (Burns and Capps, 1988): (i) *expert knowledge* of the domain being taught, that is, the ITS should "know" the subject matter well enough to be able to draw inferences and solve problems in that specific domain; (ii) *student diagnostic knowledge*, meaning that it should be able to understand the student's approach to the knowledge, detect and correct possible misconceptions, and (iii) *curricular knowledge*, in such a way that it should be able to reduce the difference between the expert and the student knowledge by means of specific pedagogical approaches.

In the next section we describe the instructional strategies that have been used in educational software design. In sections 3, 4, 5 and 6 we describe applications according to the musical activities involved, and in section 7 we conclude providing a summary and identifying areas for future research.

2 Instructional Strategies

A widely accepted classification of theories of human learning distinguishes between *connectionist* (or *behaviourist*) and *cognitive* approaches (Child, 1973), and it is particularly meaningful in relation to educational software design. While connectionist theories treat learning from the point of view of links between stimulus and response, cognitive theories emphasize the functioning of the brain and how cognitive structures modify the learner's behaviour.

Figure 1 shows the relationship, slightly adapted from Sorisio (1987), between the most common *Instructional Strategies* that have been used in educational software design and their relationship with the basic classes of the theories of learning.

Each one of these instructional strategies presents some important features:

- Programmed Learning: based on the work of Skinner (1961) in *operant conditioning*, it forms the basis for CAI. The idea behind programmed learning results in presenting frames with pre-stored material to the student. Responses to some questions should be given by the student, with the system providing comments according to the student's answers, which are simply matched to pre-stored expected responses.

[1] We will use this term throughout this paper to refer to the general class of intelligent educational tools. Other terms frequently used by researchers in the Artificial Intelligence and Education (AIEd) area include Intelligent Learning Environments (ILE), Intelligent Computer Assisted Instruction (ICAI), and so on.

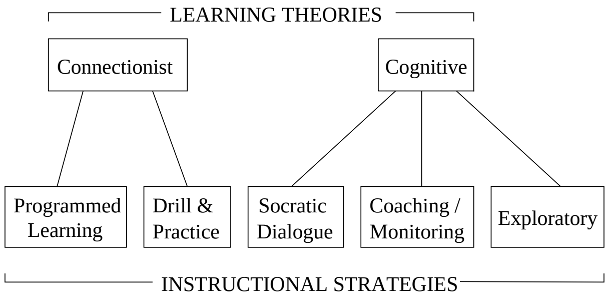

Figure 1: The relationship between learning theory classes and the most common instructional strategies found in educational software

- Drill & Practice: This strategy involves repeating a sequence of activities until the sequence is spontaneous, usually by means of a more interactive CAI to motivate the student.
- Socratic Dialogue: This is a discovery-learning strategy that relies on educational interactions in which the tutor tries to force the recognition and correction of misconceptions.
- Coaching/Monitoring: This is a strategy based on the engagement of the student in a task, while keeping track of the student's activities and giving advice when suboptimal behaviour is identified.
- Exploratory: This discovery-learning strategy encourages the exploration of a domain and usually does not include a direct tutorial component.

3 Teaching Fundamentals of Music

Most existing programs related to Music Education have concentrated on activities such as teaching Music Notation or performing "aural tests" involving recognition and dictation of rhythm patterns, musical intervals, melody patterns, chord qualities and harmonic progressions (Hofstetter, 1988). Computer-based practice allows individual students to practice in less stressful conditions if compared to group-based practice, as research suggests that students may feel less anxious about performing without a human audience (LeBlanc et al., 1997).

The most usual approach to this kind of teaching is the CAI. In fact, this was one of the first uses of computers in education in general (O'Shea and Self, 1983). The branching programs involved must consider every possible path through the frames being presented to the student. As the number of possible routes can become very large, the preparation of this kind of material normally requires a huge effort. To minimise this effort a template could be used, instead of pre-storing the questions and answers. This technique, named *generative computer assisted learning*, could control – in a restricted sense – the subject and level of difficulty of the next example according to some pre-specified strategy.

Earlier computer-based music instruction applications are reviewed by Gross (1984), and the use of CAI for this kind of teaching is revealed to be of great value, particularly in drill and practice of basic skills. A paradigmatic example of CAI in music is the GUIDO system (Hoffstetter, 1975; Hofstetter, 1981), which was used also to practise and test aural skills. Musical dictation concerning musical intervals, melody, chords, harmony and rhythm are overseen by GUIDO. These activities were accomplished through a four voice synthesiser and a touch sensitive display, with the student being invited to select an answer that best describes what he thinks he has heard. Based on the student's responses, GUIDO selects the next material to be presented and acts also on the speed of dictation or the time allowed for the answers to be given.

A significant number of commercial music instruction applications such as MiBAC Music Lessons, Music Ace and Practica Musica, most of them for teaching fundamentals of music, are reviewed by the MTNA (1996). While most of these applications use multimedia presentation techniques and MIDI devices extensively, the reviews indicate again the role of computers as highly specialised multiple choice questionnaire administrators, and the use of programmed learning and drill & practice continues to dominate this kind of teaching. However, an aural training system intended as a tool with which to experiment with different instructional strategies for ear training is currently being developed (Trewin, 1999, personal communication).

4 Teaching of Musical Performance Skills

The activities involved in the teaching of fundamentals of music may be viewed as *supportive* to the teaching of musical performance skills. These activities alone do not significantly improve the performance ability of the students (Swanwick, 1979), and other aural abilities relevant to musical performance should be developed. In this section, we describe some attempts to improve abilities such as "playing by ear" and using aural feedback to correct one's own performance.

The Tunemaster program (Kirshbaum, 1986) addresses the ability of "playing by ear", with the student being invited to play back a melody generated by the system using a touch-tablet. There is no need for previous knowledge of conventional music notation and the student is motivated through the engagement in a computer-based game.

The difficulty that students experience making fine adjustments in their own performances are addressed by Lamb and Buckley (1985) and Yoshinori and Nagaoka (1985). Both approaches use *visual feedback* in the form of a piano-roll graphical interface, and the difference between them is that the latter also presents a graphical display of expert performances. A similar approach was also used in the Piano Tutor Project (Dannenberg et al., 1990), which is an ITS for teaching the psycho-motor skills of piano playing. Its approach also relies on giving tutorial feedback on the accuracy of the novice's piano performances, but the system is supported by interactive video-disks of a human teacher and a matcher for comparing the student's performance with pre-stored expert performances. Score-following techniques are used as a basis for detecting student errors, and the student model enables instruction to be tailored to the needs of the individual student.

The development and improvement of music performance skills relies on tools with aural and visual feedback as central elements. ITS approaches supported by expert performances and score-following techniques are suitable for helping the improvement of the interpretative abilities of students as in INTERPRET (Baker, 1992), but only within the limited range of previous example pieces. The understanding of the higher level reasoning of real performers could help extend the range of the performance skills beyond pre-stored example pieces, and this was partially addressed in pianoFORTE system (Smoliar et al., 1995). A model for expressiveness in performances was developed with the help of piano instructors, and this knowledge was encoded in the system. Student's performances on MIDI keyboards are captured and visual feedback concerning expressive performance aspects such as tempo, synchronisation, dynamics and articulation are presented to the student on the original score.

5 Computers in Music Analysis

Music analysis deals with the determination of the constituent elements of a musical structure and the investigation of the functions of these elements within that structure (Bent, 1987). As a result of the obvious relationship of music analysis theories with music aesthetics and compositional theories, different views of the nature of music or the role of the human intellect with regard to music are embedded in them. This relationship explains why some music theories are mutually exclusive with other theories.

In this section we give a summary of the use of computers in music analysis as a tool for teaching or as a procedure for investigation. The applications reviewed have been used to test music theories (Baker, 1989a,b; Robbie, 1994), to check the authorship of musical pieces (Gross, 1975), or even to identify where in musical pieces established rules were observed or broken (Blombach, 1981). Computers in music analysis are typically used for event counting, sorting, pattern recognition and statistical analysis (Alphonce, 1980). All these programs recognise occurrences of pitches, notes values, intervals and also patterns and combinations of the previous musical elements.

One of the first attempts to use computers to assist in music analysis was made by (Gross, 1975). She developed a set of routines for melodic and vertical pattern scanning, thematic tracing, harmonic analysis, set theory and for keeping a cumulative count of results. Representative pieces from different musical styles composed by Bach, Haydn, Chopin and Dallapiccola were analysed, and the results were, for the most part, accurate and provided useful quantitative data.

A less generic music analysis tool intended to test the validity of music theory textbook statements about Bach chorales was developed by Blombach (1981). With this tool, it is possible to determine the range of each of the four voices, the number of times pairs of voices cross, the occurrences of parallel perfect fifths and to examine resolutions of tritones. Students find these exercises especially satisfying if they prove the textbook author's discussion inaccurate, imprecise or incomplete (Blombach, 1981).

Some aspects of the theory for tonal music analysis proposed by Heinrich Schenker (1867-1935) were implemented by Smoliar (1971, 1980) as a framework. This theory is centred on a principle of reduction (Cook, 1987; Monelle, 1992; Sloboda, 1985), in which a musical piece can be viewed as a large-scale embellishment of a simple underlying harmonic structure. Smoliar's framework enables a music theorist interactively to formulate an analysis through a compound of Schenkerian transformations.

Other theory-oriented attempts (Baker, 1989a,b; Robbie, 1994) involving knowledge-based systems have implemented aspects of the Generative Theory for Tonal Music (GTTM), one of the most influential theories of tonal musical structure (Lerdahl and Jackendoff, 1983). This theory is a step toward the understanding of musical cognition, improving on Schenker from within the paradigm of generative transformational grammar. But research should be carried out to achieve an even more complete formalisation of the principles by which the listener assigns structures to a musical piece. Some ambiguity arises if we notice the different ways that a piece of music is heard by different people, and this is taken into account by the transformational rules of GTTM. The system proposed by Robbie aims to derive interactively the groupings from a tonal piece according to the grouping component of GTTM, while Baker deals also with the time-span component.

Probabilistic and knowledge-representation based techniques supported by established music theories are the dominant approaches to music analysis. The next section presents a greater diversity of approaches to the task of music composition, as a result of this domain's more open-ended nature.

6 Computers in Music Composition

In this section, we consider applications of computers in music composition ranging from interactive educational games to specialized ITS. Teaching strategies from simple concept presentation to more exploratory approaches exist, and potential users range from novices to experienced composers.

Music Logo (Bamberger, 1974) is a representative example of the use of an interactive educational game in music composition. Its aim is to apply the ideas of the Logo Language to music, where the student learns through modelling – building and testing models. Experiments involving manipulation of musically meaningful elements support Bamberger's claims about the benefits on the construction and improvement of the pupil's musical knowledge through play (Bamberger, 1991). Some other open-ended microworlds applying Logo techniques to music composition have been built, such as that of Gargarian (1993), LOCO (Desain and Honing, 1986) and Object LOGO (Greenberg, 1988).

Other authors present interface-oriented approaches, such as a musical game involving transformations of sketched freehand curves on staves (Lamb, 1982). Operations such as time or amplitude stretching, shrinking or transposition could be applied to excerpts of the *sketched* melody producing interesting results with arguable educational value.

Styles as specific as sixteenth century two-voice counterpoint (Newcomb, 1985) and eighteenth century four-voice chorales (Thomas, 1985) have been addressed through ITSs which take advantage of the relatively well-known harmonisation rules for these focused domains. Other work is based on multiple instructional strategies for teaching basic theoretical concepts and how to use them to recognize, play and compose harmonic materials (Sorisio, 1987; Tobias, 1988).

ITS approaches based on cognitive tonal music theories for melody (Narmour, 1990) or harmony (Balzano, 1980) can also be identified in MOTIVE (Smith and Holland, 1994; Smith, 1995) and Harmony Space (Holland, 1989, 1994). MOTIVE is a constraint-based learning tool intended to be used by beginners in exploring the composition of melodies through an iconic interface based on the traditional music notation. Harmony Space is a highly interactive tool for learning about tonal harmony that is based on a representation of the harmonic relationships on a bidimensional matrix. Besides the fact that the interface is not based on the traditional music notation, the evaluation of the system indicates that with some initial guidance novices could easily navigate and produce musically interesting accompaniments. This exploratory tool gave rise to MC (Holland and Elsom-Cook, 1990), a more general framework intended to teach students how to compose tonal chord sequences being supported by a variety of guidance strategies.

Cook (1994) fosters high level compositional skills through reflection, modelling the teacher and the learner in two different roles. He presents a plausible cognitive model of how composers perceive tonality while composing. The aim of Cook's system is to engage a learner in some goal-directed, problem seeking activity in music composition and to foster the student's own ability to be reflective about the learning. In more recent work, a Knowledge Mentoring framework was used to investigate the teacher-learner interactions in the domain of musical composition, providing a taxonomy of the pedagogical goals involved in a mentoring-like way of teaching (Cook, 1998b). A teaching agent based on this framework was developed and evaluated, and the results indicate potential for the design of ITS for other domains, such as the teaching of social science, that rely on creative, metacognitive and critical thinking (Cook, 1998a)

Musical composition is not a well-defined task, and its goal could be defined as to "compose something interesting" (Levitt, 1985). As a result of such an open-ended domain, techniques ranging from interactive games without any kind of guidance to highly focused ITSs with multiple teaching strategies to support the specific needs of the students can be identified.

7 Conclusions

Computers in music teaching, in general, focus on specific tasks related to typical musical activities in an attempt to minimise uncertainties from such an open-ended domain. A number of teaching strategies ranging from simple concept presentation to more exploratory strategies have been adopted to achieve the particular educational goals. For simple musical activities such as teaching the fundamentals of music, the programmed learning approach has proved to be appropriate as most of the time these activities involves only comparing the student's answer with pre-stored templates. For the activities involved in music composition and musical performance, the dominant technique is based on cognitive theories of learning. Table 1 relates the reviewed systems with their encoded knowledge and instructional strategies.

There seems to be a lack of a complete cognitive musical theory to support musical teaching activities properly. Some progress in this direction has been made by Camboropoulos (1998) in his general computational theory for musical structure, which attempts to obtain a structural description of any musical surface independently of any specific musical style or idiom. But we suggest that there is more work to do and the search for a complete cognitive musical theory should be a high priority for AI-based music education research.

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System	*Musical Task*	*Instructional Strategy*	*Knowledge*	*Comments*
GUIDO (Hofstetter, 1988)	Music theory Ear training	Programmed Learning Drill & Practice	-	aural training and test system
MiBAC Lessons (MTNA, 1996)	Music theory Ear training	Programmed Learning Drill & Practice	-	Well-designed package for musicians
Music Ace (MTNA, 1996)	Music theory Ear training	Programmed Learning Drill & Practice	-	Easy lessons for young musicians
Practica Musica (MTNA, 1996)	Music theory Ear training	Programmed Learning Drill & Practice	-	Comprehensive music literacy program
Tune Master (Kirshbaum, 1986)	Performance Skills	Exploratory	-	Teach playing by ear using a touch-tablet
Lamb and Buckley (1985)	Performance Skills	Drill & Practice	-	Visual feedback of student performance
Yoshinori and Nagaoka (1985)	Performance Skills	Drill & Practice	-	Graphical display of expert performances
Piano Tutor (Dannenberg et al., 1990)	Performance Skills	Drill & Practice Coaching/Monitoring	User model Domain Curricular	Score following; Expert performance
INTERPRET (Baker, 1992)	Expressive performance	Socratic dialogue Coaching/Monitoring	User model Domain	Performance editing of analised melodies
pianoFORTE (Smoliar et al., 1995)	Expressive performance	Drill & Practice Coaching/Monitoring	User model Domain	Visual feedback of student mistakes
(Gross, 1975)	Analysis	-	Domain	Check authorship
(Blombach, 1981)	Analysis	-	Domain	Test theory
(Baker, 1989a,b)	Analysis	-	Domain	Test theory
(Robbie, 1994)	Analysis	-	Domain	Test theory
Music Logo (Bamberger, 1974)	Composition	Exploratory	-	Logo microworld
LOCO (Desain and Honing, 1986)	Composition	Exploratory	-	Logo microworld
Object LOGO (Greenberg, 1988)	Composition	Exploratory	-	Logo microworld
(Gargarian, 1993)	Composition	Exploratory	-	Logo microworld
(Lamb, 1982)	Composition	Exploratory	-	Free-hand curve manipulation game
LASSO (Newcomb, 1985)	Composition	Programmed Learning Socratic Dialogue	Domain	Sixteenth century 2-voice counterpoint
VIVACE (Thomas, 1985)	Harmony	-	Domain	Eighteenth-century 4-voice chorale
THE MUSES (Sorisio, 1987)	Harmony	Multiple strategies	User model Domain Curricular	Based on a harmony expert and a tutoring expert modules
Harmony ITS (Tobias, 1988)	Harmony	Multiple strategies	User model Domain Curricular	Constraint Logic used to represent the domain
MOTIVE (Smith and Holland, 1994)	Melody composition	Exploratory	Domain	Constraint-based tool focusing Narmour's theory
Harmony Space (Holland, 1989)	Harmony	Exploratory	Domain	Interactive tool based on tonal harmony theories
MC (Holland and Elsom-Cook, 1990)	Composition	Exploratory	Domain	Cognitive support framework
(Cook, 1998b)	Composition	Socratic dialogue Exploratory	User model Domain	Foster skills through reflection

Table 1: Some music education applications and their represented knowledge and instructional strategies

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