Introduction

Since the introduction of computers in music education, numerous software applications and hardware tools have been developed, leading to a variety of technology-enhanced practices to support instrumental music teaching and learning (e.g. Bauer, 2014; Brown, 2011; Dorfman, 2013; Webster, 2011). However, despite their attractiveness and their often-proclaimed added value for music learning and teaching, educational technologies remain a topic of debate. Different scholars have problematized their design (e.g. Manzo, 2011), their reception (e.g. Addessi, Pachet, and Caterina, 2004) and their implementation within the curriculum (e.g. Beckstead, 2001; Hennessy, Ruthven, and Brindley, 2005). Himonides and Purves (2010) even question whether the role of music technology for teaching and learning is actually well understood. They argue that the critical assessment of the effectiveness of these technologies should be based on empirical work that begins with well-informed theories about the alignment of technology with learning. The crucial question is how educational technologies fit with the cognitive processes and how this can be shaped for effectiveness in music teaching and learning, rather than merely providing students with a fun experience. To tackle this question requires considering the processing components that frame the interaction with technology, such as working memory, long-term memory, schema-construction and schema-automation (see Sweller et al., 1998, for more details). These processing components define a cognitive architecture that allows humans to learn from their interaction with the environment. The effectiveness of learning can then be assessed in terms of the ease with which information may be processed by the learner’s cognitive architecture (Choi, van Merriënboer, and Paas, 2014). For music education, an assessment of the effectiveness of educational technology, viewed from the prism of a well-designed cognitive architecture for music learning, is indeed much needed. The connection between technology and cognitive architecture may be decisive for whether technology enhances or degrades learning.

The goal of the present chapter is to provide a cognitive architecture for technology-enhanced instrumental music learning. The classical cognitive architecture, with its focus on working memory (Sweller, Van Merrienboer, and Paas, 1998), can thereby be used as a
starting point, but it needs refinement in view of the specific challenges that are imposed by music playing. After all, music playing requires the control of temporal structures and the articulation of pitch and rhythm in relation to expression. The educational focus on expression requires that technologies play a role in the training of the fine-motoric control that is needed for mastering musical expression. Accordingly, a cognitive architecture should give an account of the processing components that can use educational technologies in order to make the training of the fine-motoric control of musical expression more effective.

Given the current state of music cognition research, we will focus on embodiment as a determining factor for music learning (Leman, 2007). In particular, we will show that recent insights in sensorimotor processing (Maes, Leman, Palmer, and Wanderley, 2014; Prinz, Beisert, and Herwig, 2013) offer a point of departure for a cognitive architecture that covers the training of fine-motoric control for music-making (Leman, Nijs, Maes, and Van Dyck, 2015). The goal is to frame traditional music instrument learning in connection with modern educational technologies within this embodied cognitive architecture. This will then be linked with a constructivist approach to music pedagogy (Nijs, 2012; Nijs and Leman, 2014).

The structure of this chapter is as follows. First, we present a general viewpoint on embodied music cognition and show how this is linked with technology. Then we go deeper into the sensorimotor schemes that support this embodied cognition approach and show how they are linked with music learning. In the third part, we show how these insights can be related to a so-called embodied-constructivist approach to technology-enhanced music learning.

Music Cognition and Technology

Technology as a Human-Music Mediator

The development of technology has often been driven by the desire to enhance a natural interaction with the environment (Freud, 2002; Kapp, 1877; McLuhan, 1994), to reach out, to touch and to mould objects in the environment that would otherwise be inaccessible. In that context, a distinction can be drawn between music mediators and music facilitators. Music instruments are mediators. They can be seen as tools that allow the realization of natural-born abilities for music-making (Leman, 2007; Nijs, Lesaffre and Leman, 2013). Educative technologies are facilitators. They can be seen as tools that make such a realization easier, especially during the learning process. Examples are monitoring tools (e.g. Welch, Himonides, Howard and Breton, 2004), intelligent tutor systems (e.g. Fober, Letz and Orlarey, 2007), improvisation tools (e.g. Addessi et al., 2004) and musical games (e.g. Hämäläinen, Mäki-Patola Pulkki, and Airas, 2004). The rationale for using them is their capacity to make music instrument teaching and learning more effective. Their roles are different, but taken together, both instrument and educative tools provide a technology-based mediation–facilitation framework that intervenes with the cognitive architecture of the human learner.

In order to comprehend how technological mediation, facilitation and cognitive architecture fit together, it is worth considering the compatibility between body and technology. This compatibility determines, to a large extent, how the interaction with the environment will be mediated and facilitated. For music instruments this compatibility is based on how well body effectors such as arms, hands and fingers partner with the control of the music instrument, such that musical intentions (e.g. target notes, motifs and figures, and
their expressive phrasing) can be achieved in a straightforward way. The more intimate the relationship between body and technology, the more the technology becomes an inactive interface between musician and music, allowing an embodied interaction and a spontaneous gesturing of musical intentions and ideas (Fels, 2000, 2004; Nijs et al., 2013; Mulder, 2000). For educational technology, this compatibility may be focused on the arrangement for monitoring and providing feedback. Nevertheless, this arrangement may also require compatibility with the human body, as educational technologies should facilitate music playing. Compatibility highly depends upon the cognitive architecture that governs the interaction with the music-making environment. In the next section, we elaborate on this issue by considering two modes of mediation. It will become clear that the mode of mediation has a major impact on music learning.

**Modes of Mediation**

Given the mediating role of music instruments and the facilitating role of educational technology, one may consider two different mediation-facilitation modes. We call them the **prosthesis mode** and the **dialogue mode**.

The **prosthesis mode** occurs when technology is experienced as a natural extension of the human body, such that technology becomes a part of the human body. This mode is likely to happen when the music instrument, coupled with educational technology, is completely transparent—similar to the way the action of a hammer is transparent when it drives a nail into the wood. Transparency, in this context, means that the distinction between music instrument, educational technology and body effector disappears, and the entire mediation-facilitation technology is experienced as natural in achieving goals. The prosthesis mode is much in line with the idea of extended cognition (Clark, 2008), where the mind is conceived as having an extension into the environment. This is especially achieved when tools form part of the body that extend out into the environment, enabling the mind to focus on targets. The ultimate goal of having this prosthesis-technology extended cognitive functionality in a music learning context is to produce musical output, which means to be able to play the music according to a wanted expressive flavour that will affect the listener. The goal of education should therefore be to train the musician’s fine-motoric control capabilities in such a way that the used prosthesis-technology, which connects to these fine-motoric controls, becomes transparent to the musical goals (Nijs et al., 2013). Viewed from a different angle, we suggest that the production of music is the wanted sensory outcome. That outcome is achieved through action patterns that utilize effectors, such as arms, fingers, music instrument and additional tools such as scores, controllers, visuals and so on. The goal of music education should thus be to make the music instrument, and perhaps even music educational technology, transparent or mentally unobtrusive, in favour of the wanted musical outcomes that could affect the listeners.

The **dialogue mode** occurs when technology is experienced as part of the environment, such that it acts as a device that necessitates a dialogue. This would typically happen with educational technologies, although music instruments may operate in this mediation mode as well. The dialogue mode chimes with the idea of “situated cognition” (Brown, Collins, and Duguid, 1989), in which the goal is to find a way of interacting with the environment such that meaning emerges. The music then emerges from the confrontation of two inherent qualities; namely, human interaction and technology. Human interaction is based on movement, which has inherent variability. However, a music instrument or an educational
technology has its own variability or proper material characteristics, which defines the relation to human interaction. This ‘material will’ makes outcomes of human interactions less predictable, especially when compared with the outcomes that are normally achieved with proper effectors of the human body. Moreover, there are physical variables such as environmental temperature and room acoustics that may influence both the instrument and the human effectors that control the instrument, such that interaction with the instruments becomes more difficult and less predictable.

**Balancing Prosthesis and Dialogue Modes**

The question is to what extent music instruments and educational technologies can actually become a genuine mediation–facilitation environment for learning. One could argue that the music instrument, for example, will always remain distinct from the human body because it lacks ‘body feel.’ It is typically connected through haptic and tactile feedback that is established between the human skin and the material surface of the instrument (Lotze, 2013). This feedback is limited because it does not incorporate the inherent kinaesthetics of the instrument itself. In essence, the instrument is not part of our body schema; it is a mediated part that is remotely controlled. Educational technologies, with their monitoring-feedback cycles, are more distant even from the type of fine-motoric kinaesthetic feedback that instruments can offer. Therefore, they would typically operate in a dialogue mode of facilitation for learning.

There is a raft of arguments in favour of a more balanced approach, where the two modes operate on music instruments and educational technologies, and where they may even evolve from one mode to the other. For example, during the learning process there may be moments where the music instrument fully integrates with the body, where at other times the same instrument shows its ‘material will.’ Obviously, this depends on there being a familiarity with the instrument and the ease with which information may be processed by the learner’s cognitive architecture. For example, it could be that a guitarist establishes a strong unity with the guitar, while the other part of the technology, which consists of controllers that manipulate the timbre of the guitar sounds, is experienced as a technology to wrestle with. It may also be the case, however, that an added technology enhances the unity with the instrument. This is, for example, the ultimate goal of an Extended-Guitar, where certain manipulations are facilitated, that would otherwise require complex interventions on the part of the musician (e.g. retuning the instrument) and as such would be impossible to execute without disturbing or interrupting the flow of musical activity (see also Keebler, Wiltshire, Smith, Fiore and Bedwell, 2014). It is reasonable to assume that in a typical learning situation the goal may be the mastering of an instrument such that it becomes part of the human body. In practice, one may evolve from a strongly interactive feeling (the student is highly dependent on the material will of the instrument) to a feeling that the instrument has become part of the human body.

In a similar way, educational technologies may be conceived such that they fully integrate with the bodily effectors, while in other situations these technologies may work more on the basis of an interaction, without aiming towards a more intimate control of the technology. However, even as dialogue-technology, we would require that it is an effective mediator for learning, due to its compatibility with human fine-grained embodied and time-critical ways of interacting with musical tools in the environment. The difference between the two modes may be linked to the learning context (type of instrument, level of musicianship, goal
of music instruction and so on). In practice it is also driven by the ability to predict the sensory outcomes of the technology mediation, and whether cognitive attention is needed to arrive at that outcome or whether the outcome can be reached in an automated way.

Sensorimotor Schemes for Interacting With Music Technology

Having defined music instruments and educational technology in relation to embodied mediation and facilitation, we can now go into more detail about the cognitive architecture that governs this embodied processing in relation to learning. As mentioned, we need to define this in view of the training of fine-motoric skills for controlling the musical expression, and in view of assistive tools that can enhance this training. It is only through understanding the role of sensorimotor processing in music playing that we can fully understand which technologies are needed to enhance the efficiency of this training.

A useful distinction can be made between the following components of a cognitive architecture for sensorimotor processing:

- The motor command, which is the neural pattern that allows the control of the effectors (arms, fingers) that realize a musical action;
- The expected sensory outcome of the motor command, which is either imagined or predicted as the outcome of a musical action;
- The real sensory outcome: that which is actually perceived as the result of a musical action;
- The environment, which contains the technology, additional musical stimuli, the particular context.

Sensory outcomes can be kinaesthetic, in addition to an auditory or visual outcome (Lotze, 2013). For example, when motor commands are executed, one may perceive the movements of the bodily effectors (such as arms, fingers and lips for brass and woodwind instruments) as an outcome of these commands. This is of special relevance to the type of music instrument used. A pianist may imagine the sensory outcome as a fingering pattern along a keyboard, whereas for a trumpeter, this fingering pattern will be totally different, and coordinated with lip movement. Associations between expected sensory outcomes and motor commands will therefore become adapted to the particularities of the instrument, not only its sonic qualities, but also its movement qualities (the instrumental ‘feel’).

Note that the components are conceived from the viewpoint of a single person’s actions in an environment. The real sensory outcome (how the melody actually sounded), the technology (the instrument and assistive tools used), as well as other stimuli (such as musical patterns produced by other musicians, the room’s acoustical properties) constitute the person’s environment or action context, whereas the motor commands and the expected sensory outcome and perceived real sensory outcome form part of the person’s cognitive processing architecture. These components involve different types of memory. For example, the person’s motor command, the representation of the expected sensory outcome (e.g. the image of a melody and how it should be played) and the perceived sensory outcome (e.g. how the melody sounded) is information that forms part of long-term memory. When activated in view of a task, it is said to form part of the working memory.

Learning concerns the way in which the association between motor commands and expected sensory outcome can be improved (Maes et al., 2014), such that the expected
sensory outcome approaches the real sensory outcome that is generated by these motor commands, given a technology (a music instrument embedded in an educational technology) as mediator-facilitator of the motor command.

**Internal Models**

The association between motor command and expected sensory outcome can be understood as driven by so-called internal predictive models (Kawato, 1999; Wolpert, Ghahramani, and Jordan, 1995), which govern the dynamics of motor commands and expected sensory outcomes (Clark, 2013; Friston, Mattout, and Kilner, 2011). The concept of internal predictive processing was introduced in cognitive science in the early 1990s. Given the move of music cognition research towards embodiment, the importance of this concept has been increasing (Leman and Maes, 2014; Leman et al., 2015; Maes et al., 2014).

One type of internal predictive model (the so-called inverse model, or ideomotor principle) considers how sensory representation is associated with motor control, while another type of internal predictive model (the so-called forward model), considers how motor control leads to sensory representations. Together these predictive models form the core of an action–perception loop, which regulates the cognitive processing of learning. Note that learning is involved with both types of predictive processing because they can both be adapted by feedback from the environment.

**The Inverse Model, or Ideomotor Principle**

The inverse model controls how imagined musical goals are associated with the proper motor commands that realize the real sensory outcomes, so that there is a correspondence between the perceived actual (or produced) sensory outcomes and the expected sensory outcomes (i.e. the imagined goals). A good example of this ability is when a musician imagines the scale of D-major, and then knows (without thinking) how this scale should be played, so that when it is executed, it sounds as the D-major scale. Alternatively, one may apply the ideomotor principle to expressiveness, too. It simply means, for example, that a musician may imagine the expressive way in which a target note should be played, and then know (without thinking) how this target note can be realized, so that when executed, the resulting sound has indeed the desired expressive characteristic. All of this implies that the association between expected sensory outcome and motor control has been practiced and learned, using the available technology as mediator and facilitator. Typically, the learning leads to a point where the realized sensory outcomes, which have often been perceived before, have a sensory representation in a dedicated brain region. This representation can be reactivated at will, and in the context of an intended action it will result in the imagery of a wanted sensory outcome. However, this sensory outcome has always been associated with a motor command, so that the image of this sensory outcome will now be sufficient to activate the motor command needed for realizing it.

Music instrumental learning will typically train schemes that allow ideas to be translated into musical actions and fine–motoric control of the music instrument. The effect will result in a better control of musical intentionality; that is, how wanted musical goals (target notes, expressiveness) can be prepared in terms of proper embodied attitudes (posture, respiration) and motor commands (for the fine–motoric control). Educational technology can help to make this transition more fluent. A simple example would be a software application...
that generates chord labels (e.g. CMaj7, F#m7(b5)) randomly on a computer screen. The task of the musician is to play these chords and their associated scales each time a chord label appears. The challenge here is to play according to an imposed tempo that is slightly higher than the musician’s comfort tempo, so that effort is needed to reach the goal. Or stated otherwise, it is interesting to consider which technology would be needed to make the establishment of ideomotor schemes more effective.

**The Forward Model**

The forward model is concerned with the ability to control the effectors such that they automatically generate the wanted sensory outcomes. These models also allow the prediction of the sensory outcome, given the motor control. For example, when playing the D-major scale, sequences of motor commands are generated that control fingerings on the instrument. The particular order, the particular speeds and the particular co-articulation (or binding of movements) will allow the execution of sensory outcomes. While being executed, it will be possible to predict the sensory outcomes of the automated movements. Accordingly, the fine-temporal motor control can be adjusted in view of what is expected. The adjustment of highly trained sensorimotor associations may be necessary given external environmental factors. For example, when the room acoustics are different from those experienced in the rehearsed space, one may need to adapt the motor commands in order to realize the expected outcomes (Bolzinger and Risset, 1992; Maes, Giacofci, and Leman, submitted). However, in trained musicians, different schemes (learned forward models) have been formed that can be applied in order to cope with the particularities of the generated sound and the sonic feedback (Maes et al., submitted).

Instrumental learning will typically train sensorimotor schemes that make the predictability of the fine-motoric control of an instrument more accurate, in terms of the expected sensory outcomes. The effect will be that the control of sensorimotor activities will be made more efficient through schemes, so that continuous feedback and adjustment can be replaced by automatisms. Educational technology should help to train these schemes. A simple example would be a digital piano that delays the sound output, so that the student is trained to learn to play on kinaesthetic rather than auditory feedback; similar to the way in which organists play, always taking into account the sound delay due to the instruments’ mechanics and the room acoustics, which have long reverberation times (in a church setting, for example). A more elaborate example, using the Music Paint Machine, is given later in the chapter.

**Internal Models and Learning**

Attention consumes cognitive processing power, and if too much of this power is used for generating sensory outcomes (e.g. to adjust motor activity in view of continuous perceptive feedback), then this will reduce the amount available for the activation of images and musical goals, and thus for the predictive schemes. Learning will establish internal predictive models that reduce this cognitive load during instrumental music playing. In practice, sensorimotor interaction will be based on a combination of inverse and forward models so that musical intentions are combined with automated schemas that realize the intentions through actions. Education technology can improve on the efficiency for the learning sensorimotor internal schemes, provided that how it relates to these schemes is carefully conceived.
Marc Leman and Luc Nijs

Several authors have pointed out that internal predictive models, or sensorimotor schemes that are composed of inverse and forward models are hierarchically structured, so that goals can be realized in different ways (Pezzulo, 2011). Accordingly, depending on variable contingent conditions (e.g. room acoustics), schemes can exploit a repertoire of actions (e.g. slur or detach a tonal pattern) that cope with the specificities of the ‘material will’ of instruments. Schemes thus allow flexibility and motor adjustment that facilitate the prosthesis–dialogue modes of instrumental interaction.

Educational Technologies as Challenge

The mediation–facilitation roles, the prosthesis–dialogue modes and the internal predictive models (inverse–forward models) offer a framework for the assessment of educational technologies. We thereby focus on interactive multimodal educational technologies that assist in learning to play a traditional music instrument.

Interactive Multimodal Systems and Educational Technologies

Interactive multimodal systems have been used as real-time feedback systems, to display different parameters of music such as pitch and sound quality, or expressiveness, or different parameters of movement such as the bow angle of a violin. Tests of effective learning have been considered but intervention studies (using the pre-testing, treatment and post-testing paradigm) have not been used very often, and certainly not on a large scale. For example, the AMIR system uses a 3D motion capture of the movements while playing the violin and it provides a real-time visual analysis as feedback of the bowing technique (Larkin, Koerselman, Ong, and Ng, 2008; Ng, Larkin, Koerselman, and Ong, 2007). The WinSingad system focuses on sound quality and aims at complementing vocal instruction with visual feedback (Howard et al., 2007; Welch et al., 2004, 2005). The Practice Space system focuses on musical expressive timing, using a visual feedback of geometric shapes that are mapped to aspects of the playing (e.g. voice, timing, velocity) (Brandmeyer, Timmers, Sadakata, and Desain, 2011). MIROR is a platform that combines modules for piano improvisation, composition and gesture (Addessi and Volpe, 2011). It focuses on the creative explorations of young children, rather than what we have come to understand as traditional instrument training. The Music Paint Machine is an interactive educational technology that allows a musician to make a digital painting by playing music and making various movements on a pressure-sensing coloured mat (Nijs and Leman, 2013, 2014). For the examples offered earlier, real-time monitoring and feedback form the core of these educational technologies.

Interactive Multimodal Systems and Sensorimotor Learning

Interactive multimodal systems work more or less in similar ways (at least from the viewpoint of the cognitive architecture), although differences in approach and effectiveness may be considerable. Let us consider, by way of example, how the Music Paint Machine (MPM) (Nijs and Leman, 2013, 2014) relates to the cognitive architecture. The MPM uses visualizations based on a continuous monitoring of musical parameters (note duration, loudness, pitch) and movement parameters (movement of feet and torso). These visualizations (the ‘painting’) interfere with the global action–perception loop that supports learning.
To train an inverse model, the system can provide learners with a target painting that has to be ‘copied’ while playing the instrument. The target painting could be a straight line where the thickness gradually increases at first, and then gradually decreases, representing a crescendo (increasing loudness) and a diminuendo (decreasing loudness) respectively. Learners are challenged to imagine the musical goal that would realize the model painting and to generate the appropriate motor command to realize the associated sensory outcome that will copy the model. This approach also helps the development of forward models by depicting (‘painting’) the actual sensory outcome (the learner’s painting) in real time during playing. Elementary wind players would typically produce a curved line on the screen, rather than the straight line of the target, lowering in pitch as a result of the crescendo. The learner needs to adjust playing and gain control over their breathing and embouchure (use of facial muscles and the shaping of the lips to the mouthpiece). Gradually the learner will then be able to more easily predict the sensory outcome (e.g. curved line) that follows a certain motor command (e.g. lower lip pressure when aiming to produce a crescendo). The interaction can be facilitated by lining up the desired and the actual outcome, side by side, on the screen. As in other educative learning systems, the objective measurement bypasses the typical ambiguity of interpersonal feedback processes between teacher and learner (Hoppe, Brandmeyer, Sadakata, Timmers, and Desain, 2006; Welch et al., 2005).

The system’s interface allows one to customize its configuration (e.g. mappings, fine-tuning of user settings) in function of specific didactic exercises. In this way, it is possible to design instructional activities that promote the cognitive processes necessary to acquire, organize and automate schemes (germane cognitive load) while minimizing distraction due to the way learning content is presented (extraneous cognitive load) (Paas, Van Gog, and Sweller, 2010). For example, most activities in the exploration mode of the MPM are likely to promote learner control. When these activities are more or less guided (e.g. working with flash cards, Nijs and Leman, 2013), they might generate instructional activities that stimulate germane cognitive load (e.g. goal-free problems, worked examples, completion problems, Artino, 2008).

The previously described use of the MPM is an example of a direct instruction in which a learning pathway is organized along a set of separate learning experiences in function of very specific learning goals. The technology also provides a (guided) exploration mode in which the learner can explore different ways of playing the instrument and moving the body in order to create a painting as personalized creative output. While this mode can be used to afford a learner complete freedom, it can also be used to stimulate guided discovery learning, in which tasks provide non-specific goals (e.g. create a drawing using a lot of colors) to elicit certain ways of playing and moving (e.g. moving the feet a lot).

Guided exploration is interesting with regard to the construction and automation of schemes that link a temporal structure (e.g. when to play a scale note) by way of a spatial structure (e.g. the line that represents a sharp or round shape). Tasks can become more complex by involving body movements such as moving the feet, turning and bending the torso, to use different colors and transparency of colors.

The MPM is suited to train the use of sensorimotor schemes in a new and broader context (as opposed to the specific and very delineated practices in the learning path mode) so that higher-level schemes can be developed. An example is ‘playing a scale up and down’ in combination with ‘bending the torso.’ This way of creating variable conditions in which the same schemes are activated stimulates their automation (Schmidt, 1975; Schöllhorn, 2000).
In short, the MPM shapes the context through which inverse and forward models are established and integrated into schemes that underlie the learner’s interaction with music when playing a music instrument. At the same time, and following the nature of the technology-enhanced instructional design, the learning path and the experimentation mode of use can be focused on different aspects of sensorimotor processing. Obviously, this is also linked to the prosthesis–dialogue modes, where technology-enhanced learning tools facilitate the establishment of the music instrument as a natural embodied mediator. In that respect, the MPM shows how musical tasks can be set up, which the musician can reach with the instrument. Through practicing these tasks, sensorimotor schemes are developed that allow for interaction with the instrument in the prosthesis model.

**An Embodied-Constructivist Approach to Music Learning**

Educational technology, and interactive systems in particular, may contribute to an embodied constructivist approach to instrumental teaching and learning (Nijs, 2012). Arguments for this assumption are based on the multimodal character of interactive music systems, in particular their use of real-time monitoring of sound and movement and their continuous feedback on how these parameters evolve. Very often visual feedback is used as a supplementary modality that interferes with the way in which the sensorimotor schemes are developed. With the educational technology, learning can be made more effective because the cognitive processing of new information is influenced separately and independently from the traditional verbal teacher feedback which is prone to ambiguous interpretation and characterized by a delay (Hoppe et al., 2006; Howard et al., 2007; Thorpe, 2002). Moreover, the active use of body movement to control the interaction with the system appeals to the important role of the body in constructing musical meaning (Bowman, 2004; Leman, 2007).

By providing unambiguous feedback that is independent from the teacher and in real time provides information about the learners’ performance, these systems may provoke self-regulation and autonomy and, consequently, contribute to the learners’ motivation (Schunk, 2012). In addition, interactive music systems appeal to the learner’s daily reality, which is permeated with all kinds of (interactive) technological applications (Burnard, 2007; Folkestad, 2006).

Due to their specific characteristics, we believe that interactive music systems have the potential to foster knowledge construction and skills acquisition on the basis of the learners’ current knowledge and skills, their personal interests and beliefs, and their attitudes (learner-centredness). According to Mayer and colleagues (Mayer, Moreno, Boire, and Vagge, 1999), this is essential to constructivist learning. The technology supports the development of fine-motoric sensorimotor schemes that are time-critical and essential in music playing. Such systems provide the learners with feedback that contains the relevant information to develop genuine understanding and stimulates collaborative learning and dialogue.

**Conclusion**

To sum up, the educational technologies discussed in this chapter are concerned with a particular class of technologies, which are interactive and assistive. They can play a significant role in music education provided that their design and functioning is well adapted to time-critical and fine-motoric schemes that allow music instruments to become parts of player’s body. With that aim it is necessary, first, to understand the cognitive architecture that shapes the action–perception schemes and, second, to understand how educational
technology interferes with these schemes, using a prosthesis or dialogue mode of interaction. Advanced educational technologies are interactive and multimodal. They offer a new way of addressing the learning of sensorimotor schemes for music playing. However, more empirical work is needed to show the effectiveness of such systems. An assessment of those systems in the light of a cognitive architecture for learning is a first and necessary step in that process.

References


