Chapter 10

The Neurobiology of Learning: New Approaches to Music Pedagogy

Conclusions and Implications

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Brain research and educational practice

Modern societies are strongly interested in basing educational decisions on empirical evidence. Brain imaging technologies have opened a window into the active brain, attracting researchers and fascinating the public. The possibility of observing the working brain has inspired our imagination and driven us to try to understand the incomprehensible, such as cognitive processes in the conscious self, of which learning is a part (Metzinger, 2000). The increasing interest in the learning brain is reflected by recent publications that focus on the connection between brain development and learning (Blakemore & Frith, 2005; Hüther, 2002; Ratey, 2001; Spitzer, 2002, 2006; Stern, 2005; Stern et al., 2005).

This could also explain the enormous interest in the Mozart effect, which seems to offer empirical evidence that even listening to music has an impact on human cognition. It is quite obvious that music has an effect on human mood and emotion. Under certain circumstances, music can manipulate human behaviour, which is reflected through respective brain function. Although the special arousing effects of music have been confirmed, and studies have been conducted to investigate this effect as a possible means to enhance the learning process even in domains other than music (Winner & Hetland, 2000), little is known about the neural processes that constitute *music learning*: how is the brain affected by the steps and phases of music learning and, vice versa, how can specific neuronal mechanisms influence the learning of music so that, consequently, this knowledge could be systematically applied to the teaching of music in terms of developing new approaches to music education?

In so far, we aim to look at the neural correlates of learning. A neural correlate is a neural representational brain activation that directly corresponds with a particular learning activity (for definition see Chalmers, 2000). However, the possible discovery of these neural correlates does not necessarily indicate a causal connection. Moreover, much of the research in this area relies on lesion studies in which an observed disability is traced back to a particular brain dysfunction. However, we know of no "lesion studies" on learning other than those on congenital amusia (Ayotte et al., 2002; Peretz et al., 2005; Peretz et al., 2003), on the hearing impaired (Chasin & Russo, 2004) or deaf patients (Kaiser & Johnson, 2000), and especially on children with cochlear implants (Gfeller et al., 2005; McDermott, 2004; Nakata et al., 2005). In our context it would be interesting to find out whether a musical equivalent to dyslexia or colour blindness exists that affects learning. During the last few decades, a great deal of research in the neurosciences has been devoted to investigating the perception and cognition of music. Brain imaging technologies are used to locate specific brain areas where particular musical information is processed, and to document changes in the magnitude of activation caused by changes in the acoustic (musical) stimuli. Numerous studies have informed us about inter-hemispheric coherence and interaction of brain areas during the processing of music, and we know about the structural and functional changes in the brain caused by musical activities. For neuroscientists, music advanced to a cogent paradigm of neuroplasticity. However, the neuroscientific demonstration of brain activation tells us little about the functional neurobiological and neurophysiological constraints that are necessarily involved in *music learning*, that could clarify the *learning process*, and result in *musical achievement*.

Moreover, for music pedagogy it is also essential to keep in mind the limits of neuroscientific data, because they cannot provide educators with concrete rules and prescriptions for learning. Learning is always domain-specific, and music learning is its own domain, although it is linked with many other domains.

If one understands music learning in neurobiological terms as the development and gradual differentiation of mental *musical* representations and their interaction, which is at the core of neuroplasticity and enables the brain to structurally and functionally adapt to actual environmental challenges, then those functional changes can be investigated in relation to different learning strategies. However, we must consider that in no means can we assume the presence of a causal connection between some neural activation and a particular phenomenal quality. Rather, we must acknowledge that the qualitative dimension of learning cannot be read from brain activation. The only opportunity for research is to observe the possible impact of learning modes on the neural processing under strictly controlled research conditions.

The human brain always learns and is optimized for learning through evolution. However, knowledge acquisition is governed by internal conditions that are not simply manipulated by external factors. The intrinsic construction of meaning by means of implicit procedural learning is regulated by internal structures of the limbic system that are unconscious and cannot be manipulated externally (Roth, 2006), whereas the hippocampus organizes the structure of declarative memory. However, the neuro-modulatory function of the mesolimbic system (ventral striatum, nucleus accumbens) regulates the reward circuit and influences learning by emotional evaluation and transfer into long-term storage.

Beyond this, there are some general concerns with regard to scientific results and their immediate adaptability to practical applications. This is particularly true for the connection between neurosciences and music pedagogy in terms of teaching methods and curriculum development. The authors of a recently published study on educational research and neurosciences (Stern et al., 2005) argue that none of the commonly accepted principles of meaningful learning based on cognitive science, developmental psychology, or educational research has been derived from findings in brain research. Stern warns that efforts to incorporate brain research into education could cause false hopes that neuronal and educational processes are strongly and evidently linked (Stern, 2005). Another critical voice (Bruer, 1999) claims that the impact of synaptic growth and density during the early years of life should not be overestimated because synaptogenesis does not necessarily depend solely upon the quantity of incoming sensorial information, but rather on an intact sensorial perception. Cortical deficiencies in early childhood often arise from sensorial dysfunctions (Stern et al., 2005).

The common wisdom that learning is based on the plasticity of the brain requires a clear differentiation between two functionally discernible types of plasticity: *experience-expectant* and *experience-dependent* plasticity (Greenough & Black, 1992). Experience-expectant plasticity is based on the early exuberant overproduction of synapses followed by synaptic pruning, which ensures that synapses that are actually used are stabilized, and that irrelevant connections are eliminated. Thus, the normal wiring of the brain is in part a result of the kinds of general experience that have been present throughout evolution, experiences that every human who inhabits any reasonably normal environment will have. As a consequence, the brain can "expect" input from these reliable sources to selectively activate and stabilize some synapses, simultaneously causing the elimination of inactive ones. On the contrary, with experience-dependent plasticity new synapses are formed by exposure to environmental stimuli. In other words, neural connections are created and reorganized throughout life as a function of an individual's experience. For example, comparisons of the brains of animals (i.e., rats, cats, monkeys) that were raised in either complex environments full of objects to explore or in dull laboratory cages revealed large differences. The brains of the animals raised in enriched environments had more dendritic spines on their cortical neurons, more synapses per neuron, and more synapses overall, as well as a generally thicker cortex and more of the supportive tissues (such as blood vessels and glial cells) that maximize neuronal and synaptic function. This extra hardware seems to have had behavioural consequences as well: Rats raised in enriched environments performed better in a variety of learning tasks (e.g., Juraska et al., 1984; Rauscher et al., 2002). During children's developmental phases both types of plasticity are needed, and focusing only on early stimulation is as misguided as neglecting an enriched environment.

In addition to such general effects of experience on brain structure, highly specific effects can also occur. For example, rats that are trained to use either just one or both forelimbs to get a food reward have increased dendritic material in the particular area of the motor cortex that controls the movement of the trained limb(s) (Greenough et al., 1985; Tomie & Wishaw, 1990). Similar effects seem to occur in humans. For example, a study of violinists and cellists revealed that, compared with control subjects, the musicians had increased cortical representation of the fingers of the left hand (Elbert et al., 1995). In other words, after years of practice, more cortical cells were devoted to receiving input from and controlling the hand used for fingering. Similarly, skilled Braille readers exhibit enlarged cortical representations of the left hand, which is the hand they use to read Braille text (Pascual-Leone et al., 1993).

Another recent finding that evokes new expectations for learning is the discovery of mirror neurons. Rizzolatti and collaborators (Gallese et al., 1996; Rizzolatti, 1996) have discovered a population of neurons in the premotor cortex (F 5) of macaques that discharge both when the monkey performs an action or when it just observes or hears the same action performed by another individual. Researchers have speculated as to whether mirror neurons can be viewed as the missing link between the abilities of primates and language abilities in humans (Arbib, 2005). In fact, a mirror neuron system exists in humans in Broca's area -- the homologue of the monkey's area F 5. Functional magnetic resonance imaging (fMRI) studies have shown that even listening to sentences expressing an action using the hand, mouth or foot can cause activation of different sectors in the premotor cortex where the corresponding action is represented (Binkofski & Buccino, 2006). This has stimulated speculations regarding if and how mirror neurons play a role in imitation learning. In humans, mirror neurons resonate to motor movements of the hand, the mouth, and the foot that are only observed in another individual. When an action that is already present in the mirror neuron system is imitated, the act can be immediately replicated. Data from an fMRI study suggest that the coding of a viewed motor action in the mirror neuron system can be transferred to a recombination of these acts in order to replicate it according to the presented model (Buccino et al., 2004). Imitation, here, is always understood in conjunction with the learning of a novel motor act or motor sequence. The critical and still unsolved question relates to how mirror neurons function in the complex process of imitation learning. Here one has to differentiate between neuronal co-activation as a consequence of repeated practice, which causes a neuronal link between related areas (Bangert & Altenmueller, 2003) on the one hand, and the phenomenon of imitation on the other hand. The activation of the same area both in action and visual perception is different from imitation. With regard to macaques it is known that these monkeys do not imitate. Imitation is an intentional and conscious activity, whereas the activation of mirror neurons is recognized as a spontaneous neuronal reaction. At the moment, there are several conflicting opinions. Some researchers argue that mirror neurons are at the core of imitation learning (Buccino et al., 2004), whereas others concede that the actual function of mirror neurons in humans is not yet well understood (Gaschler, 2006). Nevertheless, it is clear that humans possess a comprehensive system of mirror neurons in Broca's area and the premotor cortex, representing a neuronal substrate of the meaningful processing of words (Binkofski & Buccino, 2006) as well as in the anterior insula and the anterior cingulate cortex (Hutchison et al., 1999). This would confirm and empirically explain the traditionally-established theory regarding how understanding relies on embodiment, but it does not necessarily indicate that mirror neurons enable learning through imitation. However, educators can and should make use of the fact that students activate the same neurons while observing an act as those they activate while actually performing the act themselves. This neural activation consolidates learning.

Although music educators must take into account general concerns regarding an immediate application of neuronal findings to education, they should nevertheless not ignore those findings. It might be the first time that pedagogy as a discipline can be founded – at least partly – on science. If educators are informed about the underlying neuronal mechanisms of learning, their minds may open up to new arrangements for teaching so that they can adjust their teaching to the mental state of the children. We cannot rest on the traditional belief and opinion that good teachers know about good teaching. Since the teaching environment has changed through the introduction of new media and the implementation of virtual e-learning formats, we must take advantage of all accessible resources that provide us with a clear insight into the inner structure of learning. Here, neurobiological and neurophysiological research can help shed light on the mental processes and neuronal functioning of the developing brain in order to support and enlighten our own understanding of those structures that underpin learning. A further question, then, is if and to what extent the results of brain research can be introduced into music pedagogy.

Brain research and music learning

There is a large body of observational research on the developing abilities of infants and young children that is relevant to music learning, namely structural (grouping and segmentation), rhythmical and tonal differentiation. (for review, see (Colwell & Richardson, 2002; Gembris, 1998). It has been demonstrated that infants as young as 6 to 12 months are able to recognize rhythmic distinctions in unfamiliar music after a brief exposure to this music (Hannon & Trehub, 2005). This might be due to the fact that infants are enthusiastic learners, but this learning depends on exposure, and therefore relates to the important impact of learning through acculturation. However, only a few studies focus explicitly on the neuronal substrates of music learning, and most of them are concerned with short-term learning. A neurobiological foundation of the process of learning would be extremely beneficial.

This gap can be filled by the new discipline of *Neuropedagogy,* or in European terms, *Neurodidactics* (Caspary, 2006; Herrmann, 2006; Preiss, 1998). Neurodidactics seeks to establish a brain-based learning strategy. Its goal is to adapt the teaching and learning methods to children's mental state instead of aligning children with the curriculum. The question is: what do teachers need to know about the brain that can help them to enhance their teaching more efficiently? Here, at least a few general aspects of brain-based learning can be highlighted: the supportive function of the brain-specific reward system that is turned on when an experience is better or stronger than expected, and the opposite function of stress; the importance of experience-expectant plasticity, experience-dependent plasticity, and the effects of specific types of environmental stimulation (e.g., music instruction) on brain plasticity; the function of complementary holistic experiences in which the different sensorial modalities interact with one another (e.g., what one experiences aurally can be calibrated by what one sees or feels) and generate an embodied meaning; the important impact of practical repetitions on the development of mental representations and their developing differentiation.

As to music learning, another basic mechanism is extremely important: auditory-guided vocal learning (Brown et al., 2004; Fitch, 2006; Merker, 2005). Interdisciplinary studies on the evolution of music (song) and language emphasize that music is a cultural phenomenon that incorporates a broad variety of distinct sound patterns that have to be learned through imitation by means of listening and performance (Merker, 2005). Humans, like very few animals (such as birds, dolphins, whales, and seals), possess a neuronal mechanism that enables them to imitate arbitrary sounds to which they are exposed. This is especially well investigated in songbirds' brains. Human vocalizations build upon the audiovocal ability to produce distinct sounds according to what they hear. Three neural pathways – the posterior vocal pathway, the anterior vocal pathway (with the cortex, basal ganglia, thalamus loop), and the auditory pathway – are believed to build a complex *phonological loop* that enables humans and songbirds to control their vocal production by ear (Jarvis, 2004). It has been shown that the similarities between song learning in birdsongs and language, as well as song acquisition in humans, can be traced back to a molecular level (Scharff & Haesler, 2005).

The phonological loop is also essential for working memory (Baddeley, 2003) and it plays an important role in the acquisition of acoustic signal systems like language and music. The analysis of synaptic function by intracellular recordings presents the possibility of simultaneously probing the activity of a single neuron and the synaptic network. This technique suggests that vocal learning may take place through the activation of a cancellation mechanism initiated by the auditory feedback (Mooney, 2004). In general, effective and enduring learning in daily life always happen in complex situations with interacting environmental conditions. Results from experiments with seven-months-old infants suggest that their listening preferences to familiar music were affected by the extent to which the musical extracts were removed from the musical contexts within which they were originally presented (Saffran et al., 2000). A multi-sensory representation of rhythm has also been demonstrated, particularly in young children. The perception of meters that are encoded in duple or triple form is strongly influenced by movement and bodily experiences (Phillips-Silver & Trainor, 2005).

During the process of learning, the brain links different modes of perception to executive motor skills. If a novice pianist practices finger-motor patterns every day, EEG recordings show an auditory-sensori-motor integration after just a few days of practice. Even in a silent condition, during which the subject only moves his fingers on a mute keyboard, an activation of the auditory areas occurs (Bangert & Altenmueller, 2003). This has been confirmed by an fMRI study. Pianists who observed finger-hand-movements of a pianist playing the instrument showed stronger activations within a fronto-parieto-temporal network compared to controls. Even the participating pianists who only observed silent piano playing showed activation in auditory areas. However, the extent to which mirror neuron function gets involved in this transmodal interaction must still be discovered. Furthermore, it has been suggested that an observation-execution system links visual and auditory perception to motor performance (Haslinger et al., 2005).

In an early learning experiment using DC-EEG recordings, two groups of high-school students (ages 13 to 14 years) were taught in different ways: one group by verbal instruction (explicit learning) the other group by practical performance (implicit learning). The task was to differentiate aurally between correct and incorrect musical periods (Altenmueller & Gruhn, 1997; Gruhn, 1997). Not surprisingly, both groups did not show any differences at the beginning of the study (pre-test). However, after a six-week learning phase both groups achieved higher scores on the same test items in terms of correct answers, but they differed significantly in their brain activation. In a follow-up measurement one year later, the controls who received a non-musical instruction did not exhibit any change on their test scores. On the contrary, the implicit learners retained their higher scores, but only the explicit learners showed a slight decrease of their scores. However, this result was based on a very small sample, and no statistical analyses could be performed. This study led to another longitudinal EEG study on music learning that included a larger sample of 23 high-school students (ages 12 – 14 years). Two teaching conditions were compared over more than 6 months: a procedural condition and a declarative condition. The students were taught in these different ways so that they would apply a procedural or declarative learning strategy. The procedural teaching condition was characterized by the suppression of all kinds of visual aids and verbal explanations. Rather, many kinds of vocal and instrumental improvisations were introduced. The declarative teaching condition (calling for declarative learning) was characterized by visual aids and verbal explanations, with a complete suppression of vocal production. This was done to eliminate activation of a phonological loop in this condition. This study found that the two groups exhibited significant differences in the magnitude, localisation, and distribution of brain activation depending on the method of teaching and the strategy of learning. Declarative learning was associated with an increase in brain activation over the left frontal areas whereas procedural learning produced an increase over the right frontal and bilateral parieto-occipital regions This shows that the mode of teaching significantly affects the neural processing of information and the storage and retrieval of implicit musical knowledge (Altenmueller, 2001; Altenmueller et al., 2000; Gruhn, 1997; Gruhn, 2005a). Another complementary study was concerned with intensive learning within a short time span of only 45 minutes. This study employed a similar research design as the former study. An interesting distinction was found: long-term learning over several months (see above) caused a general decrease of brain activation whereas short-term learning for only 45 minutes resulted in a general increase (Liebert, 2001). Former research studies have repeatedly demonstrated differences in the brain structure of musicians (Schlaug, 2003). Functional MRI studies exhibited a greater asymmetry in the planum temporale of musicians where the planum temporale was larger in the left hemisphere and smaller in the right than in the brains of the nonmusicians (Schlaug et al., 1995). Structural and functional changes in the brain may be attributed to early and continuous training resulting in a long-term enhancement of spatial-temporal and verbal performance (e.g., Chan et al., 1998; Rauscher et al., 1997). Consistent with findings that verbal memory is mediated mainly by the left temporal lobe are indications that musical training has a significant impact on verbal, but not on visual memory (Chan et al., 1998). A longitudinal learning experiment with young children using fMRI imaging techniques has demonstrated significant functional brain changes in the auditory cortex, the cerebellum, and inferior frontal brain areas for young instrumental students as a consequence of training (Kotynek et al., 2006; Overy et al., 2005; Schlaug et al., 2005).

In general, one can conclude from the neurobiological research on music learning that efficient learning is generally related to a decrease in brain activation, which often goes along with a shift of activation centres from prefrontal regions towards those regions relevant to the processing of particular tasks. This phenomenon is known as the *anterior-posterior shift*. Only very intense – and sometimes forced – short-term learning evokes a momentary increase of activation. In fact, this activation is immediate, but it soon disappears. Only the integration of a new ability into long-term memory generates a stable crystallized knowledge system and, therefore, should be a goal of education.

The highly-specialized forms of neuro-feedback in educational research are often neglected in this context because their application is predominantly designed for many forms of behavioural disorders (e.g. Attention Deficit Hyperactivity Disorder, ADHD) and for patients with pathological disabilities of their body functions, including complete paralysis without any form of communication. In these cases, a brain-computer-interface may help to replace the missing verbal system using an EEG-based tool (Thought-Translation-Device, TTD) (Birbaumer et al., 1999; Stern et al., 2005), but by this we enter the realm of therapy which should be separated from education.

New approaches to music teaching and learning?

Research studies have demonstrated remarkable differences in the brains of musicians compared with non-musicians in that intensive musical training causes structural and functional changes in the brain (Gaser & Schlaug, 2004; Schlaug, 2003). With respect to music learning as a more general concept of musical understanding, it was found that even the mode of learning can affect functional brain activities. Furthermore, the mode of learning is strongly influenced by the teaching method. Thus, even the teaching method has an impact on how the brain processes music. Consequently, if educators know about appropriate teaching methods that empower the brain to process musical information most efficiently, to facilitate musical representation building, and to keep the gathered knowledge accessible in long-term memory, then they can try to implement this knowledge into their actual practice. Even if not all of the following suggestions are exclusively initiated by the findings of brain research, it is nevertheless important to acknowledge that these principles are at least confirmed by findings of research studies in neuroscience.

If music learning in all its facets is grounded on the development of mental musical representations and their interaction within the neural network, it should be a primary goal of music learning to develop genuine musical representations. We should briefly explain what we mean by this. Because music is based on sound and its intentional structure, musical representations are implicit or genuine representations insofar as they represent musical sounds and sound combinations, not verbally- or symbolically-encoded knowledge *about* music (Gruhn, 2005b). Therefore, genuine musical representations are representations of music or musical elements (e.g., pitch, volume, duration, meter, timbre etc.). This is achieved when we listen to music and recognize its pulse, meter and tonality, identify themes and variations, follow parts, relate them to each other, build expectations about what could come next based upon the experience of what has been heard before. The best way to achieve this goal is to emphasize procedural and implicit learning, for research has indicated that procedural strategies seem to be more effective for long-term achievement than declarative strategies.

Furthermore, rhythm is strongly connected with movement. Therefore, the elementary teaching of tonal and rhythm patterns should always be accompanied by gentle movements so that children can develop a linked representation of motor activities and metrical weight. Another aspect seems worthwhile to keep in mind. Since vocal learning is specific to humans, and its foundation (i.e., the phonological loop), is essential for the transfer of melodic and rhythmic patterns into working and long-term memory, active music making, singing and moving are the primary modes of teaching and learning prior to any kind of verbal explanation. Furthermore, since all learning takes place in a situated and social context, context-dependent learning plays a crucial role for the meaningful learning *of* music instead of *about* music. All of this calls for a praxial approach (Elliott, 1995) because the underlying principles are strongly supported by brain research studies.

Finally, it might be argued as to whether or not it is appropriate to directly link brain research and music pedagogy and establish a new discipline that deals with the interface of neurosciences and learning. The interest in this relationship is possibly due to an overestimation of a momentarily fashionable trend. Nevertheless, the philosophy behind *Neurodidactics* underpins the necessity for the further advancement of music pedagogy in general, which cannot and should not be isolated from the powerful developments in neurosciences. What is known about brain function and neuronal processing must be shown to contribute to music education – not in terms of an immediate application of singular research findings to "brain-based methods," but in the sense that knowledge from neuroscience may help to establish a better understanding of students' difficulties in music learning and performance. Educators should try out new approaches appropriate to their teaching objectives and their students' mental states. This could enable them to adapt their teaching methods to the needs of their students for greater success and a more reliable profession.

Final Thoughts

A science that focuses on brain function, by definition, has implications for education. Although neuroscientists cannot tell educators what to teach and how to teach, educators need to know some basic information, for example, that brains have their own reward system (dopaminergic hormones) that supportively facilitate knowledge retention and faculties (Spitzer, 2002, 2006), and that external and internal rewarding complemented by slightly stressful emotions provide an appropriate principle for brain-based learning whereas mere stress and socio-emotional deprivation can affect stress-induced synaptic changes (Braun & Bock, chapter 2).

It is also important to consider that memory can no longer be seen as a passive storage of single elements, but rather as an active process of reconstructing stored templates (Braun & Bock, chapter 2). Memory is an integrative system that is based on hippocampal activities of repetitive presentations, establishing a loop between cortex and hippocampus that causes repetitive presentations so that effective and stable learning is initiated. Learning is not only and not mainly accomplished by the explicit storage of verbal (explicit) knowledge. Particularly in music, the specific musical abilities are non-verbal and don't refer to memory but to representations instead. The hippocampus plays an essential role in the formation of new memories, and functions more as a "trainer" than as a "protector" of consolidated memories.

Since music learning goes far beyond mere memorization, persistent acquisition of skills and knowledge is supported by long-term procedures of acting and practicing. Results from this praxial approach are more effective and economic (Braun & Bock, chapter 2) and cause a decrease of brain activation, whereas intensive short-term memory training calls for much stronger concentration on particular isolated items and, therefore, exhibits a significant increase of brain activation (Altenmueller et al., 2000).

What is important for music teachers to know is how to react to an observed behavior that is called "amusia" (see Altenmueller, chapter 9). In the rare cases where this can be traced back to brain damages it is a clear mental disorder. However, there are many cases that are associated with the inability to sing in tune or to differentiate between pitches. It is not quite clear whether this disability is congenitally determined or whether it is caused by a lack of environmental stimulation. If it is congenital a correction or compensation will be difficult. In this case, neural anomalies should be found that correlate with the observed behavior. Although research has presented first results that point at neuronal correlates, there is in general very little information available to date, and many questions still remain open (Altenmueller, chapter 9). Without neural correlates a teacher can hardly decide whether a deficiency in music perception and performance (singing) has its origins in genetic or social deficits. As the German Educator Donata Elschenbroich has put it: "Not to be musical is learnt!" (Elschenbroich, 2001, page number). By this statement she wants to make it quite clear that it is a social misbehaviour to restrain children from the best possible opportunities to learn and experience music. This terminates in making them unmusical, i.e. to diminishing or even avoiding their musical potential. Therefore, it is probably more often a social and political issue rather than a genetic deficit that children fail to benefit from an education according to their potential. In music pedagogy we should be very cautious not to use the classification of amusia as an excuse for not teaching these individuals. As animal research has shown, humans are prototypically imitative audiovocal learners, i.e. they are able to match pitches correctly and to integrate them(?) into a metric structure just by ear (Brown, 2007). This is equally basic in language and song acquisition. Therefore, if there is a structural brain anomaly that is responsible for a particular deficiency in the recognition of fine pitch differences, there might be other properly working abilities such as time keeping, rhythm perception, structural differentiation etc. that can also be subsumed under the term of musical aptitude (musicality, musia). Because of the complex interaction of neural processes related to music processing, it is clear without doubt that further research on so-called amusia is definitely needed for a better understanding of the actual causes of deficits in music processing in children so that educators can respond to them more appropriately.

This volume has attempted to illustrate how the educational implications of brain science are now being pursued rigorously in attempts to restructure music classrooms. Students do not appear to learn to their full potential, and yet society is demanding more and more from high school graduates and more from the school experience in general. Students in all disciplines much know more than how to repeat historical facts and execute rote mathematical procedures. Students need to acquire learning skills that apply not only to music, but across the curriculum, and beyond school as well. This can be accomplished if educational practice is based on what is known about how people learn and reason. Brain science provides this base for educational practice.

Neurodidactic researchers believe that effective educational practice should incorporate what brain scientists know about learning and instruction. The findings of brain science can, and should, serve as the foundation for instructional innovations and educational reform. The research described in this volume provides compelling examples of how brain science can contribute to educational practice.

During the past several decades, we've learned more about the brain than in all of recorded history, but there is much more to learn. As exciting as the new development in the neurosciences are, the dialogue that has begun between neuroscientists, musicians, cognitive scientists, and educators is even more exciting. For the first time, we're seeing substantive conversations between those who are conducting the research and those who are looking for applications of the research.

A start has been made, but many challenges remain for both educators and neuroscience researchers. First, we believe the research community needs to do a better job of making its methods and results comprehensible and accessible to music teachers, school administrators, and parents. End users of the research need declarative and procedural knowledge about the brain, and they need to know when and why to use that knowledge, if they are to view the enterprise as meaningful. There is a complementary challenge for educators, particularly those who control school systems, buildings, and working conditions. They must provide working and learning environments where teachers can appropriate the cognitive neuroscience perspective. Schools need to cultivate and embrace an environment that cherishes professional development, an environment that provides high-quality staff development, encourages input from teachers, and allows time for changes to occur. Finally, the neuroscience community itself must strive to assure that a coherent research program continues to evolve, a research program that incorporates the insights from cognitive neuroscience, builds on and refines the results and methods in the information-processing tradition, and pursues more recent insights about the importance of context, society, and culture for our understanding of how children learn. Given how little we currently know, research within each of the paradigms should be viewed as complementary rather than competing. We must exploit what we already know about learning and the brain, and we must strive to further our understanding. To the extent that current practices are based on common sense and outmoded theories, neuroscience research provides a needed corrective. The research in this volume illustrates how our attempts to apply research to real-world problems of learning and teaching can also serve to advance neuroscience research. Ideally, there should be continuous feedback from theory to practice to theory, and an institutional structure to support this interaction. With each interaction of this feedback loop, we would then be able to improve educational outcomes for children and deepen our understanding of learning and the brain. Rarely does neuroscience prove that a particular classroom strategy works, but the information coming from the neurosciences certainly can provide a more informed basis for the decisions we make in our schools and classrooms.

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