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The Evolution of World Music Pedagogy in the Information Society

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Abstract: *The article outlines the overarching trends and forthcoming evolution of world music pedagogy in the information society, underscoring the fusion of digital tools, neuroscientific principles, and worldwide viewpoints in music education. It aims to study neuroscientific fundamentals of amalgamating information technologies into music pedagogy, scrutinise ongoing trends, and anticipate future trajectories and challenges in technologically advanced societies. Research methods include literature review, historical-typological analysis, relative selection of promising educational technologies, and educational and prognostic-futurological modelling, followed by systematic organisation. Consequently, the article justifies the expanding synergy between traditional instructional approaches and current digital platforms, alongside dynamic methods of establishing neurosocial microenvironments to augment music education in the digitally interconnected landscape. The culmination involves synthesising neuroscientific principles, offering educational perspectives grounded in embodied cognition, artificial intelligence, and gamification, implementing a security protocol, and forecasting immediate and long-term developments in music pedagogy in the information society. These insights are expected to optimise the use of technologies as a way of enhancing music education and fostering comprehensive neurocommunication within empathetic learning communities while mitigating ethical, legal, and health-related risks.*

Keywords: *music; music pedagogy; musical art; culture; creativity; activity; neurosociety; digital technologies.*

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1. Introduction

World music pedagogy, which involves the exploration and instruction of music spanning various cultures and historical periods, has undergone profound changes within the framework of the information society. The widespread adoption of digital technologies, alongside the constant presence of the Internet and the democratisation of knowledge, has fundamentally altered the landscape of music education. Indeed, music is now disseminated, studied, reinterpreted, remixed, and shared globally. This unprecedented cultural exchange, fuelled by globalisation and the horizontal dissemination of information, has accelerated evolutionary processes, prompting a reconfiguration of world music pedagogy towards integration with complementary disciplines (Kertz-Welzel, 2015).

As cultural boundaries blur, societies become increasingly interconnected, and technologies become more accessible and sophisticated. Consequently, teachers find themselves uniquely positioned to acquaint students with musical traditions from across the globe. This presents an opportunity to nurture cultural understanding, inclusivity, empathy, and gratitude. However, the realisation of these expanded and inclusive objectives in music education necessitates a profound grasp of neuroscientific principles underlying social and cultural dynamics, complemented by innovative tools within music pedagogy to unlock and cultivate human creativity, talent, and perhaps even genius (Nerubasska & Maksymchuk, 2020).

Moreover, globalisation has fostered the emergence of hybrid musical genres and facilitated intercultural collaborations, enriching the repertoire available for study and performance. World music pedagogy in the information age must therefore strive to adapt to this evolving informational landscape and embrace this diversity. It must continue to pioneer interdisciplinary achievements, guided by the concept of neuro society, i.e., a society characterised by cerebral openness, where no realm is beyond exploration, formation, or transformation.

2. Research Relevance

Before validating the topic’s novelty, it is imperative to present several key arguments regarding the relevance of neuro- and techno-oriented music pedagogical approaches. It is generally acknowledged that among the spectrum of artistic and cultural expressions, music is recognised as the most evident, universal, and influential system of harmonised stimuli that affects individuals from a neuropsychological viewpoint, originating from both innate and technology-mediated sources (Thompson & Andrews, 2000). At the same time, investigations reveal the notable effects of music on individuals, particularly when compared to other artificial sources of influence, covering aspects from aesthetic enjoyment to the control of cardiovascular and nervous systems. As a result, music plays a distinctive role as both an educational and therapeutic tool, which requires further study in the fields of neuropedagogy and neuro-culture. Considering the rising global socio-political challenges and the urgent need to improve regional educational infrastructures, emphasis is placed on the informational environment, where education acts as a subsystem.

Analysing the situation from a wider angle, including how one’s brain and social stuff interact, is important. Music is often thought of as a universal language that does not need translation, and it has been recognised for a long time for its strong effects on one’s thinking, feelings, social connections, and overall unity. This connection happens on both online platforms and in real life, for example, at concerts, workshops, and outdoor festivals (Meriç, 2023). With the lines between music, technology, communication, and life getting blurred, working together with neurologists, educators, musicians, tech experts, psychologists, managers, and anthropologists creates a unique way to approach music education in the digital era. This cross-disciplinary involvement holds promise for enriching learning experiences, nurturing cognitive development, fostering integration, and instigating positive lifelong changes. Furthermore, neuroscientific inquiry can illuminate the therapeutic potential of digital interventions in music perception, transformation, and creation for individuals with neurological disorders, cognitive impairments, or special needs (Mino‐Roy et al., 2022).

The discourse surrounding neurotechnology within music education is fuelled by unprecedented access to global music via online platforms. This accessibility enables students and teachers to explore musical realms beyond conventional educational, geographic, and cultural confines, fostering the absorption of diverse musical traditions and fostering ongoing spiritual growth. Given that music teachers tend to fall behind in their professional development concerning the latest advancements in neuropedagogy and information technology, as well as students' digital skills, it becomes imperative to equip them with a) knowledge and comprehension of neural mechanisms underpinning learning, memory, attention, and emotional processing; b) fundamental and forward-thinking methodological principles for crafting innovative educational tools, personalised learning environments and refining the music education process in the digital sphere.

When exploring previously unexplored or controversial aspects of the issue, it is crucial to recognise the ongoing debates surrounding the relationship and determinism of neurobiological and psycho-cultural factors in music education (Schellenberg, 2020). These factors are presently being influenced by information technologies, directing their trajectory towards psycho-cultural causations, even though neurobiological investigations are concurrently gaining traction through the experimental validation of behavioural and physiological markers.

Additionally, academic literature's extensive reviews reveal a significant gap in the focus on self-directed learning and non-institutional music pedagogy despite the widespread exploration of how information technologies can enhance music education in well-equipped classrooms and broader educational settings. Acquilino and Scavone (2022) argue that the widespread availability of mobile devices and Wi-Fi networks creates new opportunities to enhance technical skills among student musicians. These technologies provide valuable support during practical sessions, helping to bridge instructional gaps even when direct interaction with teachers or mentors is unavailable. Moreover, students today demonstrate a much higher level of proficiency with information technologies than their teachers.

It follows that teachers should be able to perceive technology as an augmentative tool for enriching the learning experience rather than a substitute for traditional pedagogical methodologies. Through the integration of digital resources, interactive multimedia, and online collaboration platforms into pedagogical practice, they can fashion dynamic and captivating learning environments that align with their students' current needs and interests. However, the design and implementation of such environments for general music education require insights from neuropsychology and cultural neuroscience to protect against potential risks to psycho-hygiene, ethical concerns, and the cultural and psychological integrity of the developing and highly impressionable individual.

Thus, the article aims to explore the neuroscientific foundations of integrating information technologies into music pedagogy, identify current trends and prospects shaping the field, and anticipate the potential developments and challenges in its evolution within a technology-driven neurosociety. At its core, it seeks to bridge the "methodological gap" between the use of information technologies in music education and advancements in neurotechnologies.

To achieve this aim, the authors initially employed methods encompassing literary review and historical-typological analysis. They conducted a thorough selection process to identify promising educational technologies and applied educational modelling methods, integrating prognostic and futurological approaches. These included expanded modelling and simulations of real-life behavioural scenarios within neurotechnological educational environments. Additionally, their work involved generalising broader educational phenomena, including key principles, trends, expectations, and potential risks.

When exploring topics rooted in the concept of "development", one must contextualise recent historical advancements and maintain continuity. In this regard, the authors examined the prerequisites and historical discourse surrounding the evolution of music pedagogy in the information society. The investigation revealed the enduring relevance of the relationship between the educational music environment and technological advancements (Braun, 2002; Kertz-Welzel, 2021; Schippers, 2009). This historical continuum underscores the necessity to maintain such activities, particularly as one transitions into the initial decades of the 21st century. Notably, the authors draw inspiration from the methodological contributions of practitioners who have long recognised the synergistic interplay between music, pedagogy, and information technologies, predating the widespread embrace of such a paradigm.

Indeed, Zoltan Kodály (1974), a Hungarian composer and educator of the mid-20th century, formulated a pedagogical method centred on music education through vocalisation, bodily movement, and solfeggio. Long before the emergence of neuroscientific research, he integrated principles of kinesthetics, synaesthesia, and embodied cognition into music pedagogy. Despite originating before the digital age, Kodály's methodologies (1974) resonate with today's educational paradigms that integrate multimedia and multisensory modalities in the examination of cultural artifacts, musical composition, and related domains.

It is also crucial to acknowledge Shinichi Suzuki (Suzuki & Suzuki, 1993), a Japanese violinist and pedagogue, within the context of this investigation. He devised an educational approach aimed at instructing music to young children within a nurturing environment reminiscent of language acquisition, viewing it as a neurophysiologically determined perceptual-semantic system (Peak, 1996). His educational philosophy, which includes audio recordings, group sessions with parents, and the activation of neurophysiological mechanisms akin to secondary signaling pathways, opens up significant opportunities for applying early learning neurotechnologies.

Similarly, German composers and educators developed a methodology encouraging creative expression through bodily movement, speech, and improvisation. They claimed that the awakening of one's "inner music" motivates them to embrace musical instruments or explore other avenues of spontaneous creativity. Today, educators have adapted these principles by combining digital technologies with interactive participation to foster spontaneity and creativity among students (Goodkin, 2001).

Furthermore, various innovators and music educators explore the confluence of music pedagogy and technological advancement. Some have studied neurotechnological methods of syncretic learning, where rhythmic movements, improvisation, and physical expression form integral facets of music education (Findlay, 1995).

These notions regarding the interconnectedness of cognitive processes with bodily experiences, encompassing movements, gestures, language, and even vocalisation, within the framework of pioneering technologies and advancements in neuroscience, have the potential to evolve into a novel paradigm of comprehensive music education. The definition and potential of this paradigm will be explored in the third section of this article.

Therefore, the international relevance of this research lies in its ability to enhance the understanding of how musical resources, now accessible through innovative digital technologies and interdisciplinary fields such as neuropedagogy, neurosociology, and cultural psychology, can enrich both educational and neurosocial fields.

3. Neuroscientific Aspects of Music Pedagogy in the Context of Information Technologies

The neuroscientific study of music, viewed through psychological and anthropological lenses, is being explored in depth across multiple dimensions. This includes research on neurological activity (Marin & Perry, 1999) and the cognitive-behavioural mechanisms that influence perception and performance (Justus & Bharucha, 2002). It also examines the neurobiological and neurosocial implications of absorbing musical heritage, as highlighted by Kraus and White-Schwoch (2017). The wide scope of these investigations points to the potential for an extensive discussion in a specialised review publication.

Notably, Habe's observations (2010) underscore the substantial advancements achieved within the neuropsychology of music since the 1990s. These advancements are characterised by a confluence of clinical and non-clinical investigations, prominently featuring the identification of underlying mechanisms, functional dynamics, and operational modalities of the brain during processes of musical perception and creativity across normative and pathological contexts. This knowledge base is increasingly informing conventional pedagogical practices. This article attempts to outline the main neuroscientific aspects of music pedagogy able to catalyse its advancement within the context of information technologies.

The first one is *neuroplasticity*, historically viewed as the brain's ability to adapt and reconfigure in light of novel stimuli but currently regarded as the most dynamic neuro-attribute characterising the technologically immersed younger demographic (Zhang et al., 2022). Redirecting attention to music pedagogy, it is noteworthy that music perception inherently operates within neuroplasticity. Whether individuals engage with music via passive listening or active use of information technologies, it has a significant impact on the perceptual dynamics of musical experiences. Additionally, the proliferation of innovative tools and platforms has significantly streamlined processes associated with music creation, exploration, and interaction. Platforms such as digital audio workstations (DAWs), virtual instruments, application,s and music composition software afford children flexibility in manipulating sound elements and creating musical compositions. However, this engagement among young people is typically exploratory and experimental, often tied to recreational activities or expressions of affinity for particular musical subcultures. As a result, educators face the challenge of incorporating these practices within the broader structure of music education curricula.

The efficacy of music pedagogy benefits from the *heightened receptivity* of young individuals to musical trends, providing such education with distinctive emotional and cognitive advantages. Nevertheless, forward-thinking teachers must leverage technological accessibility and a diverse array of musical resources to involve students in a wide range of emotional and cultural experiences beyond fleeting musical trends. Simultaneously, the inherent social and cultural sensitivity of adolescents and young adults will play a pivotal role in this activity. Through engagement with music, children consciously apprehend the multifaceted diversity of the world while subconsciously internalising musical archetypes that facilitate an understanding of natural, geographical, and ethno-genetic diversity. This phenomenon is anticipated to transpire not exclusively via the engagement of brain regions associated with social cognition and emotional processing (Kayne & Kullar, 2022) but also through the nuanced individual modalities of empathetic and aesthetic valuation of melody and its neuro-cultural environment.

Subsequently, it is essential to study the neural underpinnings of music and cultural education programs. Positioned within cultural education, music pedagogy encompasses the acquisition and assimilation of cultural knowledge, values, and practices, often facilitated by studying diverse musical traditions. The neuroscientific inquiry has revealed functional neural correlates linked to cultural education, including the activation of mirror neuron systems, theory of mind networks and the hippocampus (Jacob, 2008; Mara, 2017). Within today's information society, music pedagogy possesses the boundless potential to dynamically construct or grant access to cultural environments in real time via multimedia resources, using digital platforms to create authentic cultural experiences for learners and potentially enabling virtual collaborations with musicians or cultural ambassadors. Unfortunately, one can observe the absence of neurovisual confirmation regarding the correlation between music and other abstract neurocultural phenomena.

Nevertheless, their existence can be inferred from extrapolations derived from studies examining the relationship between musical aesthetics and physiological forms of satisfaction. Significantly, advanced neurovisual research by Mara (2017), involving a large sample of over 700 participants, demonstrated the activation of the corpus striatum, ventromedial prefrontal cortex, and insular regions across different reward modalities. However, functional dissociation was evident, depending on the type of reward, with a shared network but distinct signalling pathways. Therefore, the indication of the "biological utility" of abstract rewards opens up broad opportunities for integrating music pedagogy with simulation technologies, addressing the diverse and often pronounced hedonistic tendencies of children and adolescents.

Following these conclusions, it is crucial to explore the information-technological dimensions of *neurophysiology* in music education. Research indicates that multimodal learning within music pedagogy significantly influences brain development. Music education frequently incorporates multisensory activities such as listening, performing, manual rhythm coordination and visual interpretation of musical notation, engaging various brain regions, promoting neuronal integration and yielding more resilient learning outcomes. One may assume that in the era of information technology, digital tools, interactive visual aids, virtual instruments, and immersive audio-visual experiences can enhance the efficacy of general music education in mainstream schools. Still, systematic integration of neuroeducational strategies in this context primarily serves children with sensory disorders, developmental challenges, or other special educational needs, typically with a compensatory intent (Lyndina et al., 2023).

At the same time, the paramount factor remains the unique *neurocognitive* profile of each student, influenced by genetic predispositions, environmental factors, and personal experiences. Within the information society, music pedagogy can accommodate neurodiverse students through customised learning experiences, adaptive technologies, and personalised feedback mechanisms. Acknowledging the remarkable subjective neurodiversity and the diverse musical content, one should recognise the continual need for music teachers to refine methods, approaches, and technologies in real time during instruction. This process, known as "fine-tuning," involves guiding educational-musical performance by adjusting the "malleable" neuroenvironment within the group and taking into account the students' individual sensitivities. This approach aims to better align with their unique needs, preferences, and skill levels, facilitating learning and comprehension with minimal teacher intervention (Berbets et al., 2021). At a methodological level, adaptation of educational content (variant component), feedback mechanisms, and learning environments is imperative.

4. Music Pedagogy and Technologised Neurosociety: Methods, Trends, and Development Prospects

Following the principle of holography, which involves the repetition of system structures at different levels, one can confidently suggest that the educational system, environment, and even individual classrooms engaged in perceiving, studying, and reflecting on music at specific times and places employ similar toolkits and operate under uniform neurosocial laws. This assumption is particularly true in musical or educational-musical settings, which have been instrumental and psycho-cultural since their inception, thus justifying such extrapolation. Over the past 50 years, this extrapolation has been supported by consistent trends observed in two neurotechnological modes, namely, online (individual) and real (group) (Acquilino & Scavone, 2022).

In music pedagogy, which primarily focuses on transmitting artistic heritage to students, it becomes crucial to balance the "cutting edge," appealing to the sensitivities of youth perception, and the profound traditions. While the informational environment tends to encourage the consumption, creation, and transformation of today's music, it primarily serves as a platform for heritage preservation. Nonetheless, some neurosociologists argue that the formation of artistic preferences and the development of taste and aesthetic needs are more influenced by neurogenetic factors than environmental ones (Franks, 2019; Greenberg et al., 2022). This is especially relevant in the context of general aesthetic universals and imaginative perception, which, according to Franks (2019), evolve with historically changing neurosensitivity, shaped by the ideals that emerge within creators and expressed through their feelings and premonitions in the language of poetic and imaginary images of diverse worlds. Consequently, integrating synthetic genres or using technological capabilities for remixing and remaking traditional or classical music in line with current trends within the general music education curriculum can significantly enhance youth interest and the quality of assimilation.

The authors of this article are conducting an extensive longitudinal study of adolescents, following them from the onset of puberty at age 12 until they turn 16, which coincides with the completion of their schooling. It is anticipated that within each surveyed class, there will be several students displaying enthusiasm for computer design, programming, or other innovative applications of information technology in transforming, remixing, or arranging music. Additionally, initial surveys have revealed that 67% of students regularly or occasionally listen to popular pop, rock, or electronic music.

The findings of this ongoing investigation will soon be shared with the wider public. Meanwhile, the authors anticipate an increase in student engagement with remixing activities in the experimental groups, indicating a potential rise in the successful integration of traditional heritage, involving established cultural backgrounds, with a focus on national, diverse, traditional, and classical features. They suggest that even minimal, personalised, or collective technological enhancements by students in the area of musical heritage, like beat processing, stylisation, arrangement, or incorporating electronic effects, can elevate the neurocultural awareness of youth regarding musical trends and bridge the divide with traditional musical values.

To create structured approaches and educational systems in music that are relevant to the information age, the authors support the use of a neurosociological behavioural model, similar to the inherent dynamics of neurobiology. Here, civilization, culture, city, group, and individual are viewed as equivalent contributors to communication (Franks, 2019). This neurosocial communication promotes horizontal interactions, avoiding institutionalism and hierarchical structures. It enables the implementation of behavioural modelling in music teaching, which is shared by both neurobiological and social frameworks (modelling – role-playing – feedback – execution) (Sakai, 2014). This educational model can be influenced by guiding principles that align with the evolving demands of society. Societal expectations for education, combined with insights from neurocognitive research, facilitate the distillation of nonlinear and holistic educational principles into a few fundamental points. Crawford's (2014) concept is especially compelling as it highlights relevance, authenticity, and multidimensionality as core principles in forming the "phenomenon of the whole person" through music education. These principles can confront the challenges and progress in music pedagogy, presenting them through specific neurotechnological viewpoints (see Table 1).

Table 1. Findings from neurotechnology regarding the advancement of music education in accordance with Crawford's theory (2014)

Principle	Pedagogical insight into music	Neurotechnology's impact on the authenticity and organic nature of its use
Relevance	The division between the established value of musical heritage and the current value of youth music trends.	Neurotechnological advancements can help bridge the "gap" between classical values and the sociocultural needs of students.
Authenticity	Given the ethnic-regional educational context, music education content and adaptable technologies should align collectively while catering to students' priorities, experiences, tastes, and methods of absorbing musical content.	Possibilities to optimise the consideration of students' neurosocial and neurocultural profiles in music education.
Multidimensionality	It integrates various educational objectives, ranging from students' interests, perceptions, and passion for music to fostering creative self-expression and cultural awareness and cultivating an aesthetic and critical understanding of musical culture as it evolves.	The capacity to naturally inspire and motivate students through multi-channel and multi-activity methods, encompassing both technological and cognitive-behavioural dimensions.

Source: the authors' own conception

Musical creativity software is becoming increasingly versatile, ranging from simple smartphone apps to advanced digital audio workstations (DAWs). These tools enable students to compose, arrange, and produce music using virtual instruments and sample libraries. Through collaborative online projects, students with varying levels of skill and interest can collaborate to arrange, perform, or remix classical and traditional music using digital audio software. This may involve blending classical pieces with current genres, experimenting with electronic music production techniques, or reimagining traditional folk songs with today's instruments. While these possibilities are presented as desirable, the main challenge in the complex and information-rich world is aligning these technologies with the cognitive-behavioural objectives of music education programs, ensuring that perception and response to music are central markers of success (Bauer, 2020).

The authors' selection of methods and technologies, based on their neurotechnological potential, has allowed identifying embodied cognition, gamification and AI use as the areas for the closest and most effective methodological development in music pedagogy. These choices stem from a systematic analysis detailed in the subsequent paragraphs.

In embodied cognition, there exists corroborated evidence of cerebral synergy within music-drama performances, particularly within the context of inclusive education. While the specific educational impacts are currently being assessed in the short term (Mino-Roy et al., 2022), it is essential to conduct long-term, longitudinal studies following the application of the proposed methodologies. However, the potential for advancing world music pedagogy lies within local and regional educational settings, where vibrant, authentic environments can be enriched through embodied music cognition technologies and digital resources. Successful research, such as Staveley's dissertation (2020) on the integration of embodied music cognition and neuroscientific advancements, provides valuable insight. Staveley (2020) found that this integration enhances the participants' imagination, emotions, and physical actions (including teachers and moderators), allowing them to create and manage dynamic, transient musical experiences. These experiences facilitate multifaceted communication, intentional movements and dances, virtual journeys, cultural immersions, and other key neuroeducational outcomes. As a result, this approach boosts student motivation through mechanisms of increased satisfaction, exemplified by collective empathy and transcendent experience.

Moreover, the music's aesthetic, collective experience within a multi-channel framework reduces ethical constraints and social inhibitions. This often leads to involuntary rhythmic movements, vocalisations, and even spontaneous dancing in conducive environments. As a result, music pedagogy becomes more closely aligned with psychotherapeutic principles.

The authors of this article propose the "Interactive Music Making" methodology for educators, based on an observed learning pattern. *Music making* is understood as an active, immersive experience that involves creation, performance, improvisation, and emotional connection with musical structures. This approach integrates digital technologies, body movement, interactive visualisation, and other neuroeducational methods.

Rooted in the integration of musical perception, motor activity, and emotional immersion, the methodology promotes deeper learning through embodied cognition. Rather than passively listening or analysing, students actively create, experience, and interact with music. Through movement, improvisation, collective sound-making, and, when possible, augmented reality, they engage with music on a multisensory level, making the educational process more user-centric and captivating.

The effective ways of using this methodology include the following:

1. Engaging with Music through a Multi-Layered Experience. Students explore music using multimedia presentations, sensory stimuli, or immersive digital experiences like VR or AR. They communicate musically by using their voices, gestures, and physical responses.

2. Improved Motion and Engaged Interaction. Engaging in rhythmic movement and dance improvisation enables students to connect with music physically. The application of free-form motion, which involves spontaneous or chaotic gestures, encourages the expression of emotions. This leads to collaborative musical modelling, where students interact and co-create lively “musical words” through their movements.

3. Emotional and Cultural Connections to Musical Experiences. By investigating musical traditions from different times and cultures, students achieve a deeper understanding of the significance of music. Accordingly, interaction cultivates a sense of collective empathy, turning music from a personal experience into a shared social dialogue.

4. Consideration and Unification of Life Experiences. Students engage in reflection and integration of their experiences, contemplating their emotional and sensory responses following immersion. They examine the role of music in shaping their movements, spatial awareness, and group interactions, leading to a richer understanding of its effects on perception and expression.

AI incorporation into musical neuropedagogy offers considerable potential, yet it demands meticulous execution. Studies have shown that AI improves neuroeducational music training by allowing for tailored learning experiences, fostering human-like interactions within a multi-semiotic framework, and creating a flexible setting for enhancing cognitive and sensorimotor abilities (Yu et al., 2023). By using machine learning techniques and extensive data analysis, AI systems can detect individual patterns of musical perception and tailor learning strategies accordingly. This allows one to create AI-driven platforms capable of monitoring students’ attention through neurofeedback or analysing performance expressiveness. These systems can then dynamically adjust the complexity of creative exercises in real-time.

Li and Wang (2024) have experimentally validated the effectiveness of AI-powered chatbots in piano instruction. Their findings reveal a nearly 7% increase in musical performance and engagement, whereas improvements in less creative disciplines, such as solfège and music theory, were significantly smaller. This underscores a strong neurocognitive connection between music, learners, and AI.

Despite these promising results, the field is still in its early stages, with a lack of established and thoroughly tested protocols for student-AI interaction in music education. A comprehensive analysis of both risks and potential benefits has led to the development of a pilot algorithm for implementing this methodology (see Table 2).

This algorithm is believed to enable teachers to effectively integrate artificial intelligence into music education, fostering personalised, adaptive, and creatively driven student development. However, its effectiveness must be empirically tested, which will be the focus of future research.

As previously mentioned, the authors of this article have also identified gamification as a promising technology for advancing general music education. In addition to their informational capacities, gamified educational instruments comprehensively consider the inherent needs, capacities, and cerebral neuro-mechanisms involved in children’s cognitive and emotional engagement (Antonopoulou et al., 2022).

In briefly examining these perspectives within music pedagogy, the primary argument centres on the neurosocial and neurophysiological aspects of “non-musical” play. Elements of gamification, such as completing quests, achieving goals, and receiving sensory rewards, can be integrated into music education technologies to inspire students and heighten their involvement. Through feedback loops, virtual rewards, social incentives, and other gaming features, students are motivated to engage in the learning process and pursue music with dedication.

Table 2. An algorithm for integrating artificial intelligence in music education with a focus on neuroscience

Stage	Methodological step	Teacher/student action description	Tools/ technologies
1. Diagnostic assessment of musical and cognitive features	Evaluating music perception and cognitive skills	Conducting diagnostics on auditory memory, rhythm sense, emotional sensitivity, and reaction time	Neurofeedback systems, adaptive music tests (ToneGym, Melodics)
2. Personalising the learning path	Setting individual learning parameters	Selecting appropriate task difficulty, learning pace, and musical styles based on AI analysis	Interactive platforms (Yousician, SmartMusic, AIVA)
3. Interactive musicking with AI	Using adaptive accompaniment	Students improvise or perform music, and AI adjusts the accompaniment in real time based on dynamics and tempo	Virtual teachers (Flowkey, Skoove), generative AI (MuseNet, Magenta)
4. Feedback via neurofeedback	Real-time analysis of progress	Using sensors to assess concentration, emotional state, and engagement	Neurointerfaces (Emotiv, Muse), biometric analysis (Eye-tracking, HRV)
5. Adaptive learning strategy	Dynamic adjustment of exercises	Automatically modifying task difficulty or stylistic variability based on progress	AI-driven learning process analytics (Tonara, Soundtrap)
6. Creative improvisation and composition	Fostering creativity through musical exploration	Students compose original pieces with AI assistance in generating harmonic, melodic, or rhythmic options	Generative music models (OpenAI Jukebox, AIVA)
7. Collaborative interaction and socialisation	Using shared AI platforms for group work	Organising ensemble activities or virtual collaborations with other students using interactive services	Online studios (BandLab, Soundtrap, Endlesss)
8. Reflection and final analysis	Discussing achievements and emotional insights	Facilitating discussions about experiences, challenges, and discoveries during the learning process	Performance recording and analysis, emotional diaries, progress visualisation on AI platforms

Source: the authors' own conception

Furthermore, music-pedagogical gamification technologies should soon incorporate "fine-tuning" capabilities. This will enable the regulation not only of the theme and nature of the course, such as a music-historical quest, but also the neuro-parameters, including intensity, control, and rewards. In this context, the concept of "playing within the game" or double play becomes relevant, as music represents an abstract, symbolic-sound reflection of life, while gamified technologies operate on simulation principles.

In this regard, the authors propose the "Audio Modelling" methodology, which integrates cognitive neuroscience, music pedagogy, and interactive learning through experimentation. This approach uses software tools (DAW, virtual synthesisers, audio effects) for active manipulation of sound parameters (such as pitch, volume, timbre, reverb, and panning). Establishing new connections between sensory, motor, and cognitive areas of the brain promotes students' neuroplasticity, with the teacher actively engaging alongside the students. Below are the practical steps and stages for its implementation:

1. *Auditory Analysis and Modelling*. Students listen to sound samples and recreate them by modifying parameters within the software (for instance, changing the waveform on a synthesiser or applying effects).

2. *Experimental Interaction*. Students experiment by creating their variations of sounds and rhythms, exploring how changes in different parameters affect their musical perception.

3. *Compositional Improvisation*. Both students and the teacher independently create short musical segments by manipulating sound characteristics.

4. *Reflection and Comparison*. Together, the teacher and students analyse the results, compare them to reference sounds, and reflect on the emotional and cognitive impact of the changes in the sound.

It is now important to study broader perspectives regarding the advancement of music education within the context of the information society. For instance, Sakai (2014) explored the intersection of music-cultural pedagogy and the networked society. This work draws upon critical pedagogical principles and sociological theories to address challenges stemming from the postmodern digital music culture. Central to this discourse is the inquiry into how to uphold the democratic role of criticism amidst the swiftly evolving cultural landscape (Sakai, 2014). However, the past decade has witnessed significant transformations, not only in the realm of information technology but also in broader neurosocial contemplations concerning global technological advancements, geopolitical shifts, and other paradigmatic alterations. Consequently, it is necessary to speculatively anticipate and model the imminent evolution of world music pedagogy, with an active engagement in critical-reflexive technological discourse by educational stakeholders.

This descriptive framework includes various perspectives, anticipations, and prognostications, encompassing not only potential benefits but also foreseeable risks and limitations (see Table 3).

The distant future holds promise for interdisciplinary collaboration among music education, information technologies, and neuroscientific advancements, positioned within educational futurism. This promise will materialise as tools become refined and more accessible. The authors outline their trajectories for the remote advancement of music pedagogy, rooted in expanded modelling and simulation of real human behavioural scenarios and cognition, aligned with anticipated high-tech innovations (see Table 4). This discourse begins with a consideration of a recent publication by Gkintoni et al. (2023), which undertook a comprehensive review of neuroscience's role in today's education, emphasising the necessity of upholding human rights, social values and neuroethics, namely, a critical consideration in light of potential threats posed by emerging technologies, notably artificial intelligence and augmented reality.

Table 3. Predictions for the advancement of music pedagogy at the forefront

Vector	Vector exposition	Implementation status
Technology integration	The incorporation of digital tools and neuro-psychological principles will continue to engage students and influence sensory experiences in music education, particularly through the use of virtual reality (VR) and augmented reality (AR).	In progress
Global collaborative learning	By facilitating neuro-social and sensory interaction, information technologies will enable students, educators and musicians from diverse backgrounds worldwide to collaborate on musical projects, share cultural ideas, and gain insights from different perspectives.	Anticipated
Cultural diversity and inclusion	Music education programs and technologies will increasingly prioritise fostering cultural diversity and inclusion. This focus will broaden the exploration of various global musical traditions, genres, and practices, while simultaneously diminishing cultural segregation, isolation, and marginalisation.	Part of pilot projects
Neuroadaptive technologies	Adaptive music learning systems, AI-driven recommendations, and personalised feedback mechanisms will closely align with students' needs,	In progress

	interests, and learning styles.	
Interdisciplinary approaches	By integrating real-life experiences with insights from anthropology, neurosociology, cultural studies, and digital technologies, students will gain the ability to sense and comprehend the social, historical, and cultural contexts surrounding global music traditions and innovations.	Part of pilot projects
Experimental and project-based learning	Emphasis will be placed on hands-on learning experiences rooted in technology-driven projects, enabling students to actively immerse themselves in world music through performance, composition, improvisation, and multimedia creation.	
Teacher professional development	Continuing education programs, seminars, and online courses will help educators stay updated on emerging trends and innovative practices in world music pedagogy.	In progress

Source: the authors' own conception

One should be cautious of speculative and hasty interpretations of the proposed neurotechnological applications. Therefore, interdisciplinary research collaboration and expert ethical assessment should precede such innovative educational interventions. This will be facilitated by cooperation among lawyers, educational managers, neurologists, music educators, technologists, and cognitive psychologists. Thus, ethical discussions regarding issues of digital psychohygiene, confidentiality, and evidence-based research will serve as important guidance for the responsible implementation of these technologies in educational institutions.

Table 4. Anticipated trends in music pedagogy with the integration of neurotechnologies

Vector	Benefits	Risks and limitations
Personalised learning through the brain-computer interface	Monitoring the neural activity of students during musical practice enables real-time feedback (neurofeedback) for adaptive interventions tailored to students' cognitive states.	Legal, educational, and neuroethical regulations and preemptive measures are necessary to mitigate potential harm from interventions.
Virtual reality (VR) and augmented reality (AR) as tools for full immersion in music education	It can transform music education by fostering an immersive learning environment where students engage with virtual instruments, simulate performance venues, and explore musical concepts in a multidimensional space.	Potential concerns include reliance on simulated environments, neurophysiological disturbances, the necessitating establishment of clear protocols, time management guidelines, parental consent, and other related considerations.
Democratisation and universal access to educational technologies, modularised by AI	Unrestricted access to online learning platforms, virtual classrooms, and AI-powered digital resources will promote the most effective and inclusive music education for students from diverse backgrounds and age groups, irrespective of their geographical location or socioeconomic status.	It necessitates financial and organisational resources, supervision from parents and educators, as well as educational monitoring.
Brain stimulation methods for enhancing cognitive abilities.	Transcranial magnetic stimulation (TMS) and transcranial direct current stimulation (tDCS), both non-invasive brain stimulation methods, can improve cognitive functions associated with music learning, including auditory perception, motor coordination, and memory consolidation.	Following extensive research, it is imperative to establish ethical and medical safety protocols for implementing these methods.

Source: the authors' own conception

Finally, it is important to discuss the neuroethical and neurohygienic challenges that come with technologised music education. While the use of "brain-computer interface" (BCI) technologies, virtual and augmented environments for music learning, and personalised auditory influence algorithms offer new possibilities, they also raise significant neuroethical and neurohygienic concerns. These issues are becoming central to the debate on relational rhetoric (Weh, 2024). This article identifies at least three main problem areas.

First, when integrating BCI, the question of autonomy and control is raised as a critical issue, particularly regarding the extent of control students have over the neuro interface. There are also concerns about the potential for subconscious manipulation of students' attention, concentration, or emotional reactions. This requires transparent data processing algorithms and safety protocols that ensure a clear distinction between neurostimulation for educational purposes and potential cognitive interference. Second, the psychological effects of virtual environments in music education need further investigation. Immersion in VR or AR for musical experiences can alter the sensory perception of real-world soundscapes, which, over time, might lead to sensory dissonance or a decline in critical listening skills. Therefore, methodologies should incorporate adaptive shifts between digital and real-world music practices. Third, equitable access to advanced technologies remains a pressing concern. High-tech music education platforms are often commercially limited or require complex technical setups, which can create barriers to access, especially for students facing socioeconomic or physical challenges.

These reflections prompt the development of framework recommendations to tackle these challenges. The authors of this article believe that these recommendations should focus on: a) establishing ethical standards for the use of BCI and VR in music education, with an emphasis on preserving students' cognitive autonomy; b) creating "ecological" neuro-digital practices – a balanced alternation between technologised and acoustic music-making to maintain cognitive equilibrium; and c) designing open adaptive platforms that provide access to musical learning environments for users with diverse levels of skill and ability. Implementing these protocols will help mitigate cognitive risks and ensure that neuro-oriented music education is effective, safe, and inclusive. A standard protocol could be outlined as shown in Table 5.

Table 5. A preliminary safety protocol for technologised music learning (considering neuroethical and neurohygienic challenges)

Safety category	Risks and challenges	Proposed safety measures
Neuroethics and autonomy	Potential interference of BCI in cognitive processes, manipulation of attention, and subconscious neurostimulation.	1. Using transparent BCI algorithms with explanations of how they work. 2. Allowing users to control the level of stimulation and deactivate it. 3. Regular testing of neurostimulation for unwanted effects.
Neurohygiene and cognitive health	Sensory dissonance, overload of the auditory and visual channels due to VR/AR.	1. Alternating digital music-making with acoustic music (50/50). 2. Implementing breaks every 30-40 minutes of active digital immersion. 3. Using adaptive technologies that adjust the level of stimulation based on the student's condition.
Psychosocial impact	Emotional dependency on virtual environments, and reduced sensitivity to real sound.	1. Implementing reflective practices after each VR/AR session (discussion of sensations). 2. Controlled access to immersive technologies – no more than 30% of total learning time. 3. Using VR/AR only under the supervision of educators.
Inclusivity of access	Socio-economic inequality in access to music technologies.	1. Developing open educational platforms with free content. 2. Using budget-friendly technologies (mobile apps, adaptive devices). 3. Introducing universal design for users with special educational needs.
Data confidentiality	Accumulation of sensitive neurodata, risk of its use without user consent.	1. Implementing anonymised storage of neurofeedback data. 2. Establishing clear rules for data access (only with user consent). 3. Using local data storage instead of cloud storage (whenever possible).

Source: the authors' own conception

It is important to highlight that this protocol should be tailored to specific educational programs and students' skill levels. Before implementation, testing in control groups should be carried out to evaluate its effectiveness and identify any potential risks.

5. Conclusion

In an era characterised by rapid technological advancement, it is imperative to grasp the trajectory of world music pedagogy within the framework of the information society to effectively incorporate digital tools, advancements in neuroscience, and diverse global perspectives into music education. This examination illuminates the convergence of traditional teaching methodologies, current digital platforms, and the establishment of neurosocial microenvironments for music education in an interconnected digital landscape.

In this context, there is a need for educational adaptation to consider students' perceptions, responsiveness, interests, engagement, enthusiasm, evolving trends, the influence of youth subcultures, and the reinterpretation of classical heritage in a technologically enhanced learning environment.

A detailed analysis of neuroscientific principles behind the problem in question shows that the links between advanced technologies and students' neurocognitive features significantly affect how music pedagogy develops. In the information society, music education is expected to meet students' different neuropedagogical needs through offering personalised learning experiences and assessments. In the context of musical processing, personalised teaching methods and techniques can improve learning outcomes for students with and without special needs. Importantly, neuroplasticity lies within the perception of music and the use of IT. In doing so, it ensures an effective interaction between these fields and enhances cognitive skills.

Accordingly, this article supports the idea of reconsidering curricula on music education due to the "embodied cognition" concept. This method cultivates students' engagement and feedback, including such activities as listening, meditation, and dancing. Besides, play activity is seen as an efficient neuro-component that aims to define the future of music pedagogy.

The brain's neurophysiological processes that motivate movement in response to music include synchronization with rhythms, the activation of mirror neurons, involvement of the brain's reward pathways, stimulation of the motor cortex, and a collective emotional experience. These mechanisms work together to create a unified and physical experience of music, prompting natural movement and expressive reactions that should not be limited by conventional school behaviour standards.

Conversely, the systematic incorporation of diverse art forms (particularly theatre, music, and dance) will foster syncretism and produce a synergistic outcome.

This article's arguments underscore that in the evolution of world music pedagogy and culture, the social, physical, and anthropological dimensions act as concomitants of music, aesthetic sensitivity, and somatic reactions within nonverbal communication and empathetic resonance. In this parallel relationship, one could metaphorically suggest that technologies enhance the body and mind's abilities through their sensory and transformative functions, while the perception and learning of music naturally serve as enjoyable extensions of educational and social communication.

The primary outcomes of the article encompass outlining the frameworks of the "closer" (prospective) and more distant (futurological) models, as well as highlighting valeological-ethical and legal limitations, risks, and challenges.

The first model, as of the current writing, exhibits varying degrees of implementation and encompasses Technology Integration, Global Collaborative Learning, Cultural Diversity and Inclusion, Neuroadaptive Technologies, Interdisciplinary Approaches, Experimental and Project-Based Learning, and Teacher Professional Development.

The second model examines more speculative territory, offering futurological projections for the evolution of music pedagogy within the realm of neurotechnologies. Anticipated changes include personalised learning through the “brain-computer” interface, the use of virtual and augmented reality for immersive music education experiences, democratisation of access to educational and musical technologies, modular AI integration, and the application of brain stimulation techniques to augment cognitive capabilities.

The proposed neuro-oriented music learning methods include several approaches. First, there is “Interactive Music Making,” which emphasises emotional and motor engagement with music. This is achieved through multidimensional communication, improvisation, and cultural immersion. Another method is the algorithmic integration of artificial intelligence. This system tailors learning experiences, analyses students’ cognitive characteristics, and adapts music tasks in real time. Finally, there is “Audio Modelling,” which promotes neuroplasticity. This method allows students to actively manipulate sound parameters, experiment, and engage in compositional improvisation. As a result, students gain a deeper understanding of musical structures and their influence on emotional states and cognitive processes.

The authors also acknowledge the neuroethical and neurohygienic challenges associated with technologised music education. These challenges include ensuring student autonomy when using BCI interfaces, maintaining sensory balance in VR/AR environments, and making innovative methods accessible to all students. To address these issues, they propose a standardised protocol. This protocol includes the development of transparent algorithms for controlling neurostimulation, alternating between digital and acoustic music-making, and limiting VR/AR usage time. Additionally, it emphasises the creation of open educational platforms that prioritise inclusion and data security. The goal is to ensure effective, secure, and equitable access to music education for all.

Thus, the progression of music pedagogy in the information society offers significant opportunities for extracurricular education, including individual, online, and self-directed learning. It also supports technologically enhanced educational environments that promote authentic empathetic group interactions immersed in a techno-cultural context of holistic neurocommunication.

By exploring the neural mechanisms behind music perception, cognition, and behaviour in the digital realm, one can use music’s transformative power to nurture creativity, build social connections, and improve cognitive well-being across diverse student populations. Adopting an interdisciplinary approach that combines insights from neuroscience, education, and emerging technologies is crucial for advancing music education as a catalyst for human growth and prosperity in the digital age.

6. Research Limitations

The authors of the article employed theoretical methods and did not verify potential approaches to advancing music pedagogy through practical experimentation. Moreover, it is imperative to explore the ethical and health-related consequences of the swift progress of informational neurotechnologies within the educational-musical domain.

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