

REVIEW ARTICLE

Educational innovation and active musical practice in teacher training: A socio- perspective

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Abstract

This article presents a theoretical review of the integration of emerging digital technologies into the initial training of primary school music teachers, analyzing this process from the perspective of science and technology studies. Based on a critical review of recent literature (2010–2024), the trends, approaches, and challenges in integrating digital tools, virtual learning environments, collaborative platforms, sound-production applications, and generative artificial intelligence systems into music teacher education are identified. The analysis draws on theoretical frameworks from the science and technology studies field, particularly the social construction of technology, studies on technological systems, and debates on appropriation, agency, and power in educational digital environments. It is argued that digital technologies are not neutral artifacts: their design, distribution, and adoption in educational contexts are shaped by power relations, economic interests, cultural dynamics, and political decisions that directly affect formative processes. The review shows that pedagogically meaningful integration requires, beyond technical skills, a critical understanding of the sociotechnical dimensions that configure these technologies. It is concluded that 21st-century music teacher education needs to articulate active practice and bodily expression together with critical reflection on the technological devices and platforms that mediate such education.

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1. Introduction

Education is immersed in a profound transformation driven by technological advancement and the digitalization of sociocultural environments. Schools, teacher-training institutions, and teachers themselves face the challenge of integrating digital tools and innovative methodologies to meet the demands of a connected and rapidly changing society. This context requires not only a rethinking of what to teach, but also of how to teach and learn, promoting critical and creative digital literacy.¹ However,

from the perspective of science and technology studies (STS), this process cannot be reduced to the mere incorporation of tools: it also requires asking who designs these technologies, in what socioeconomic contexts they are produced, what values they embed, and who benefits from them^{2,3}, a concern that critical theorists of technology have long argued cannot be separated from questions of rationality and democratic control over technical design.⁴

For prospective primary school teachers, this transformation means that professional training must include not only classical disciplinary competences, but also digital competences, innovative teaching approaches, and the capacity for critical reflection on the technological artifacts that mediate their pedagogical practices. However, many teacher-training programs still rely on traditional models of knowledge transmission, which hinder both the organic integration of educational technologies and the problematization of the sociotechnical conditions in which they operate.⁵ The challenge, then, is not only how to train teachers to use technology, but how to train them to critically understand the technologies they use.

Music education offers particularly fertile ground for exploring these tensions. Music not only stimulates cognitive development but also fosters aesthetic sensitivity, divergent thinking, emotional expression, and identity construction.⁶ In primary teacher training, music can serve as a cross-cutting axis that simultaneously strengthens communicative, motor, social, and artistic competences. At the same time, the incorporation of digital tools in the music classroom digital audio workstations (DAWs), sound-collaboration platforms, and generative artificial intelligence (GAI) applications raises specific questions about authorship, creativity, embodiment, and the experiential dimension of musical learning that are not found with the same intensity in other disciplines.

Active musical practice, learning by “making music,” and bodily expression take on special relevance as pedagogical mediations that connect the body, emotion, and sound. Incorporating movement, gesture, and bodily participation into music classes fosters rhythmic internalization, creative expression, and a meaningful experience of sound.^{7,8} From an STS perspective, it is crucial to ask to what extent the introduction of digital technologies into this space enriches, or conversely displaces, these experiential and embodied dimensions of learning.

The general aim of this study is to analyze the contributions of digital pedagogies and educational innovation to the musical training of prospective primary school teachers, from a sociotechnical perspective that problematizes the conditions of production, distribution, and use of emerging digital technologies

in this field. Specifically, the article seeks to: (i) identify the STS theoretical frameworks relevant to the analysis of technological integration in music education; (ii) characterize emerging digital technologies according to their sociotechnical specificities; and (iii) explore the implications of these dimensions for the design of teacher-training programs in the field of music.

The relevance of this approach is justified by the current historical context. The COVID-19 pandemic dramatically accelerated the digitalization of educational environments, exposing both the potential of technologies and their structural limitations: access gaps, dependence on private platforms, and the loss of the bodily and relational dimensions of learning. In the field of music education, this acceleration was especially significant: the suspension of in-person classes particularly affected a discipline that, by its very nature, requires bodily presence, shared sound, and collective experience. Post-pandemic reflection on which technologies to adopt, under what conditions, and with what implications has thus become an urgent necessity for the field.^{1,9}

Additionally, the emergence of GAI systems from 2022–2023 onward has profoundly transformed the technological landscape in music education, raising radically new questions about authorship, creativity, and the teacher’s role as mediator between student and technology. This study aimed to contribute to that reflection by applying conceptual frameworks from the STS field to critically consider the relationship between technology, society, and education.

2. Theoretical framework

2.1. Science and technology studies: A framework for thinking about digital music education

Science and technology studies constitute an interdisciplinary field that examines how social, cultural, economic, and political factors influence the production and use of science and technology, and how these, in turn, shape society.^{3,10} In contrast to deterministic views that conceive of technology as an autonomous force that inevitably impacts society, the STS field has developed constructivist perspectives that emphasize the contingent and negotiated nature of technological artifacts.

One of the most influential frameworks is the social construction of technology (SCOT), developed by Pinch and Bijker¹¹, which proposes analyzing technological artifacts in terms of the relevant social groups that participate in shaping them, the technological frames that guide their design, and the processes of closure and stabilization that fix their meanings. From this perspective, a DAW such as

GarageBand is not simply music-production software: it is an artifact whose design reflects decisions about what type of user is imagined, which musical practices are privileged, and which business models sustain its distribution (in this case, integration within the Apple ecosystem).

Winner² posed the well-known question of whether artifacts have politics, arguing that technological objects embody specific forms of authority and values that are not neutral. Applied to music education, this implies asking: what conceptions of musical creativity are encoded in artificial intelligence (AI)-assisted composition algorithms? What pedagogical models do corporate-designed collaborative platforms favor? What is left out when musical training is mediated exclusively through commercial digital interfaces?

For its part, actor-network theory (ANT), proposed by Latour¹², conceptualizes sociotechnical systems as networks of human and non-human actors that interact to assemble, shape, and stabilize one another. In the educational context, this invites an analysis of how teachers, students, devices, platforms, curricula, and institutional frameworks co-configure pedagogical practices. A music class that incorporates AI is not simply a class with an additional instrument: it is a different sociotechnical network, with new distributions of agency, new dependencies, and new asymmetries.

Finally, contemporary debates on the political economy of digital platforms^{13,14} contribute a critical dimension regarding the structural conditions under which educational technologies operate. Platforms such as Google Classroom, Soundtrap, or even the most widespread GAI tools respond to logics of data extraction, monetization, and market expansion that are not irrelevant when considering their use in training environments. The “platformization” of music education entails transferring pedagogical practices to private infrastructures whose governance escapes the control of educational institutions, a dynamic that STS-informed studies of educational data infrastructures have documented across school systems more broadly, showing how commercial platforms reshape pedagogical relationships and institutional decision-making from within.¹⁵

2.2. A sociotechnical taxonomy of emerging digital technologies in music education

From an STS perspective, it is essential to analytically distinguish among the categories of digital technologies used in music education, given that their differences are not merely functional but above all sociotechnical, economic, and pedagogical. Grouping them under the generic term “emerging digital technologies” without analytical

distinction may obscure precisely the dimensions that the STS field is best equipped to illuminate.

The first category comprises DAWs: programs for multitrack recording, editing, and music production. Examples such as GarageBand (Apple), Soundtrap (Spotify/Google), and BandLab (BandLab Technologies) share the function of sound production but differ significantly in their business models (proprietary/free/freemium), their ecosystems of dependence (Apple hardware, Google infrastructure), their user communities, and the models of musical production they favor. Soundtrap, for instance, was acquired by Spotify in 2017, situating its development within the logic of the music-streaming economy and its interest in training new content producers for its platform. GarageBand, meanwhile, is designed as an entry point to the Apple ecosystem, with predefined loops and templates that facilitate production but also delimit the aesthetic horizons accessible to the non-expert user.

The second category comprises digital collaborative platforms: networked work tools such as Jamboard (Google, discontinued in 2024), Padlet, or Miro. These platforms were not designed specifically for music education but rather for corporate project management environments, and their adoption in education is a process of appropriation that is not always free of tension. The discontinuation of Jamboard in 2024 illustrates the vulnerabilities entailed in supporting educational processes on corporate platforms whose continuity depends on business decisions unrelated to pedagogical needs. From the SCOT framework, this situation can be interpreted as a failed closure process: the platform had been stabilized by the educational community as a co-creation tool, but the more powerful social group, the owning corporation, imposed a different closure.

The third category, qualitatively different from the previous two, is GAI: systems that, trained on large corpora of data (in this case, musical data), are capable of generating new sound content, accompaniments, scores, or texts about music. Relevant examples include Artificial Intelligence Virtual Artist (AIVA), MuseNet (OpenAI), Suno.ai, and Soundraw. These tools raise specific questions for music education that are not shared with the previous categories: what musical corpus was used to train the models, and who authorized that use? To what extent does GAI-assisted composition reproduce the aesthetic and cultural biases of the training data? What do authorship and creativity mean in a context where the system generates material that the student then selects and edits?^{16,17}

This taxonomic distinction is not merely classificatory: it has direct implications for the design of teacher training. Incorporating a DAW into musical training entails

pedagogical objectives and ethical issues distinct from those raised by the use of a GAI system. Conflating both categories under the umbrella term “emerging digital technologies” without analytical distinction is one of the deficits that the STS field can help to overcome.

2.3. Digital pedagogies and educational innovation

Digital pedagogies can be understood as educational approaches that use, integrate, and articulate digital technologies for pedagogical purposes, promoting active learning, interaction, collaboration, and creativity. In music, this can manifest as cooperative digital projects, musical gamification, and virtual environments for composition or sound editing. However, as Selwyn^{9,18} notes, the rhetoric of technological educational innovation tends to reproduce a celebratory view that obscures power relations, access inequalities, and implementation failures. An STS perspective on digital pedagogies, therefore, implies not only asking what technologies can contribute but also what social relations they produce and what costs they distribute.¹⁹

Educational innovation, in this context, entails moving from transmissive teaching toward active, creative, student-centered experiences, in which learning is constructed through intervention, experimentation, and co-creation. In music education, innovation can manifest in the design of sequences in which students compose, improvise, collaborate, record, and share their productions, or even visualize them using digital tools.²⁰ From an STS perspective, it is important to note that this innovation does not occur in a vacuum: it is conditioned by institutional frameworks, available technological infrastructure, current education policies, and professional teaching cultures, which can either enable or hinder processes of change.

A key element for these proposals to be feasible is the development of teacher digital competences articulated with artistic and expressive competences. Teachers must be able not only to use software, but to integrate it with pedagogical purpose in musical projects and to reflect critically on the sociotechnical conditions of those tools. In the Spanish context, specific adaptations of the Common Framework for Teacher Digital Competence have been proposed for the musical field²¹, although these adaptations rarely incorporate an explicit STS dimension that problematizes the structural conditions of the technologies used.

The notion of teacher digital competence has evolved from an instrumental conception, knowing how to use tools, toward more complex conceptions that include ethical, critical, and civic dimensions.⁵ In the STS field, this

evolution is welcome but insufficient unless it explicitly incorporates the capacity to analyze technologies in relation to their conditions of production. A digitally competent teacher is not only one who knows how to use a DAW or a GAI system: it is one who can reflect on which corporate interests designed that tool, what data it collects, how the use their students make of it is monetized, and what alternatives exist. This dimension of digital competence, which could be termed sociotechnical literacy, is precisely what the STS field can contribute most distinctively to debates on digital teacher training.

In the field of music education, research on pedagogical innovation has identified several promising lines of work: project-based learning around digital music projects, in which students create, produce, and disseminate their compositions through digital platforms²⁰; the use of musical gamification to motivate the acquisition of technical and theoretical skills; the design of active-listening experiences mediated by sound-analysis tools; and the incorporation of podcast production and audiovisual material as a way of reflecting on musical experience. All these proposals share a commitment to active and meaningful learning, although they rarely incorporate a systematic reflection on the sociotechnical conditions of the platforms they use.

2.4. Music education in primary teacher training

Music in the curriculum of prospective primary school teachers should not be considered a secondary or complementary module, but an essential component of artistic literacy. It enables the development of capacities that transcend the musical: auditory sensitivity, temporal awareness, motor coordination, creativity, and social competences. Through music, teachers can design cross-curricular interventions with other areas of the curriculum (language, mathematics, science), enriching students' educational experience.

From an STS perspective, music education is also a space in which conceptions of which music deserves to be taught, which technologies are legitimate for producing it, and which models of creativity are pedagogically valid are negotiated, a negotiation that, following sociological accounts of taste as a marker of social distinction, is never merely aesthetic but also reproduces class-based hierarchies of cultural legitimacy.²² The incorporation of GAI tools in the music classroom, for example, reactivates unresolved debates about the relationship between human creativity and algorithmic production, the distinction between composers and performers, and the value of the formative experience relative to productive efficiency. These debates are not purely philosophical: they have concrete curricular and formative consequences.

Traditionally, music teaching in teacher training has privileged approaches centered on score reading, instrumental technique, or music theory lectures. While these components have value, they are insufficient unless accompanied by practices that foster the experiential dimension of sound, improvisation, conscious listening, and experimentation.⁸ The introduction of digital technologies can enrich these practices, but it can also reproduce, in digital format, the same transmissive and technical emphases of the models it aims to overcome, if it is not accompanied by pedagogical and critical reflection.

The value of bodily expression and movement in music education lies in the body becoming the mediator of time, rhythm, and musical phrasing, functioning as a biological mediator that transfers physical sound energy into musical meaning and back again, as theorized within the embodied music cognition tradition.²³ Through movement, we internalize pulses, accents, and silences. Studies in neuroeducation indicate that motor development influences musical processing and that bodily expression helps address musical rhythm in the school context.²⁴ In teaching environments, embodiment helps to foster a more integrated relationship between mind, body, and sound.⁷ From an STS perspective, the bodily dimension of musical learning also reminds us that musical training cannot be reduced to what occurs on digital interfaces: the body is a sociotechnical actor that cannot be replaced by any platform.

In this sense, the pedagogy of Émile Jaques-Dalcroze, whose rhythmic method based on bodily movement dates from the early 20th century, takes on renewed relevance in the context of digital music training. The Dalcrozian principle that the body is the first musical instrument, and that rhythmic understanding necessarily passes through the bodily experience of musical time, constitutes a weighty argument against reducing musical training to its computable dimensions. Similarly, the Orff pedagogy and the Kodály method emphasize active participation, collective singing, and movement as the foundations of musical learning, a perspective that contrasts with models of individual learning mediated by digital interfaces, which tend to privilege GAI and automated sound-production platforms.

The tension between these active pedagogical traditions and new technological possibilities should not be resolved by substituting one for the other, but through their reflexive articulation. An STS approach to the history of music-education methodologies can reveal that both active methods and digital tools result from specific social and historical processes, and that their integration into teacher-

training curricula responds to institutional, cultural, and economic contexts that warrant critical analysis.

2.5. Integrating digital pedagogies into music training

For music teacher training to be relevant in the twenty-first century, it is essential to incorporate specific digital tools that facilitate experimentation, sound creation, and collaboration. From an STS perspective, this integration must consider not only the tool's functional possibilities but also its conditions of production and the sociotechnical implications of those conditions. The main categories of tools are:

- Sound composition and editing applications (DAWs): Platforms such as Soundtrap, BandLab, or GarageBand allow prospective teachers to create, mix, and edit musical pieces digitally. Recent research has shown that using DAW tools in teacher training enhances creativity, meaningful learning, and motivation.²⁰ However, these platforms operate within specific corporate ecosystems whose economic logic influences their pedagogical design.
- Digital collaborative platforms: Tools such as Padlet or Miro can be used to co-create scores, share ideas, and organize collective compositional projects. It is important to note that these platforms, originally designed for corporate environments, present conditions of use, data policies, and business models that deserve critical examination in the context of teacher training.
- Generative artificial intelligence systems: tools such as AIVA, Suno.ai, or Soundraw allow the generation of musical material through algorithms trained on large corpora. Their use in music education raises specific questions about authorship, creativity, intellectual property, and the cultural biases of the training data.^{17,25}
- Audiovisual resources and podcasts: the design of sound material, music podcasts, or sound stories as a teaching resource fosters critical listening, aesthetic analysis, and creative production.²⁶

Nevertheless, one of the major challenges is integrating technology without losing the bodily and expressive dimension of music. Technology should not replace the body but complement it. For this reason, digital activities should be articulated with moments of movement, bodily improvisation, or musical dance. From the perspective of ANT, this can be interpreted as the need to keep the body as a relevant actor within the sociotechnical network of the music classroom, rather than allowing it to be displaced by the digital interface.

2.6. Active musical practice and bodily expression as pedagogical mediations

Active musical practice functions as a methodological axis when students (prospective teachers) learn through action: playing, singing, improvising, and actively participating in music an experiential logic consistent with Kolb's model of learning as a process grounded in direct experience²⁷, and with the broader conception of music as an activity rather than an object, famously captured in the notion of "musicking" as the totality of doing, performing, and relating around sound.²⁸ This modality fosters the internalization of rhythm, deep listening, and musical self-confidence. Bodily expression acts as an educational-musical language that connects mind, body, and emotion. Through gesture, movement, and bodily space, students perceive musical concepts experientially (rhythm, accents, silences, phrasing). Research indicates that the use of bodily expression in music improves motivation, peer relationships, and musical learning²⁹, and that embodiment constitutes a privileged resource for understanding the cognitive connections between rhythm and movement.²⁴

From an STS perspective, the centrality of active practice and bodily expression in musical training can also be read as a form of resistance to reducing musical learning to its computable and quantifiable dimensions. The musical body, with its variability, its affectivity, its relational and unrepeatable dimension, cannot be fully captured by any algorithmic tracking system, nor replaced by any generative AI. This bodily irreducibility within the STS field provides an argument for maintaining active practice as the core of training rather than treating it as an optional complement to digital tools.

2.7. Challenges and prospects

The implementation of digital pedagogies in arts training faces institutional challenges: inadequate technological infrastructure, poor equipment maintenance, resistance to change, and a lack of specialized training. These challenges are not purely technical or pedagogical: they are also sociotechnical, insofar as they reflect political decisions concerning resource allocation, curricular priorities, and teacher-training models.²¹

From an STS standpoint, one of the most relevant challenges is the dependence of public teacher training on private technological infrastructures. This dependence creates vulnerabilities that become apparent when platforms change their terms of service, raise their prices, or are simply discontinued, as occurred with Jamboard. The sustainability of digital pedagogical innovations

therefore requires education policies that consider not only the provision of devices, but also the governance of the digital infrastructures used in teacher training.

Another important challenge is equity and technological accessibility in diverse educational contexts. Not all prospective teachers have regular access to devices, connectivity, or robust resources, so proposals must be designed with flexibility and adapted to heterogeneous conditions. From the STS field, this digital divide is not a technical problem solvable with more devices: it is a manifestation of structural inequalities that require political responses.

3. Methodology

This research was based on a systematic literature review conducted from an STS perspective, aimed at analyzing how digital pedagogies, active musical practice, and bodily expression influence teaching-learning processes in the initial training of primary school teachers, and how the sociotechnical dimensions of emerging digital technologies configure these processes.

3.1. Literature selection criteria

Articles, books, theses, and academic reports published between 2010 and 2024, in Spanish and English, were selected based on their focus on the integration of digital tools and multimedia resources in music teaching; active musical practice (singing, improvisation, body percussion, collective creation); bodily expression and movement as pedagogical mediators in music education; the application of AI and virtual environments in teacher training; and STS applied to educational contexts.

Regarding the Spanish-language literature, the 2010–2024 period was examined using the following strategy: for 2010–2019, priority was given to studies on music teacher training, digital competences, and bodily expression in the Spanish-speaking context, mainly through Dialnet, Redalyc, and specialized journals such as *Revista Electrónica de LEEME*, *Eufonía*, and *Retos*. For 2020–2024, the search was broadened to include studies on GAI and education, digital educational innovation, and teacher training in Spanish-speaking countries, where recent academic output reflects the acceleration of the post-pandemic debate on technological integration. The concentration of references between 2023 and 2025 in the Spanish-speaking area aligns precisely with this dynamic: it is in this period that the greatest density of publications on GAI and music education in the Spanish and Ibero-American context occurs, which does not diminish but rather confirms the temporal relevance of the study.

Studies that did not address initial teacher training, focused solely on professional music education without pedagogical relevance, and STS studies without connection to educational contexts were excluded.

3.2. Analysis procedure

The review was structured in several phases: (i) a search for sources in Scopus, Web of Science, ERIC, Google Scholar, Dialnet, and Redalyc, using keywords such as “digital pedagogy,” “music education,” “active learning,” “body expression,” “AI in education,” “social construction of technology,” “STS education,” and “platformization of education”; (ii) selection and categorization of documents; thematic synthesis around four axes (technological innovation, active musical practices, expressive mediations, and sociotechnical dimensions), following the principles of thematic analysis³⁰; and (iii) critical interpretation, evaluating the validity of the studies, their limitations, and their implications for teacher training. The STS perspective was incorporated as a cross-cutting axis of the analysis, rather than as an isolated category, allowing the findings of each axis to be problematized through the field’s theoretical frameworks.

The five analytical categories presented in [Table 1](#) were derived from the four initial thematic axes through an iterative coding process consistent with the phases of thematic analysis proposed by Braun and Clarke.³⁰ After an initial round of open coding, in which excerpts from the reviewed literature were labeled according to the four a priori defined axes (technological innovation, active musical practices, expressive mediations, and sociotechnical dimensions), two members of the research team independently reviewed the coded excerpts and identified that the technological-innovation axis grouped findings differed substantially in their sociotechnical implications: those concerning DAWs and collaborative platforms, on the one hand, and those concerning GAI, on the other. Given the qualitatively distinct ethical, authorship-related, and regulatory questions raised by GAI, this axis was split into two differentiated categories: integration of digital pedagogies and GAI in music education. At the same time, a set of recurring codes related to teacher profiles, professional development, and digital competence frameworks that did not fit within any of the four original axes was inductively grouped into a fifth category: development of critical teacher competences, following the constant-comparison logic typical of thematic analysis. Discrepancies in coding and category boundaries were resolved through discussion until consensus was reached. The resulting five categories were then used to organize the correlations among

findings, implications for teacher training, and reference authors presented in [Table 1](#).

3.3. Ethical considerations and validity

As this is a literature review, no human participants were involved. Validity is ensured through triangulation of sources and the critical review of high-impact literature, prioritizing studies with transparent methodologies and replicable results.³¹ The incorporation of STS theoretical frameworks adds a dimension of interpretive validity, situating the findings within broader social, economic, and political coordinates.

4. Results

The thematic analysis of the selected studies, conducted from an STS perspective, identified five main categories that synthesize the trends, contributions, and challenges surrounding the integration of digital pedagogies, active musical practice, and bodily expression in the initial training of primary school teachers.

4.1. Integrating digital pedagogies: Possibilities and sociotechnical conditions

Recent studies show growing interest in incorporating DAWs, such as Soundtrap, BandLab, or GarageBand, into the training of prospective teachers. These tools promote creativity, autonomy, and meaningful learning by enabling the collaborative creation, editing, and dissemination of musical productions.^{20,21} However, the studies reviewed rarely problematize the conditions of production and distribution of these tools, their business models, or the implications of public teacher training’s dependence on private infrastructures.

A relevant finding from an STS perspective is that the adoption of collaborative platforms in Spanish-speaking educational contexts has been mediated by their free or low-cost availability, which has fostered dependence on corporate tools whose governance escapes the control of educational institutions. The discontinuation of Jamboard in 2024, a platform widely cited in the Spanish music-education literature, illustrates this vulnerability and the need for digital-sovereignty policies in education. From the SCOT framework¹¹, this can be interpreted as a tension between pedagogical closure (the stabilization of Jamboard as a music co-creation tool) and corporate closure (Google’s decision to discontinue it).

Likewise, collaborative platforms such as Padlet and Miro facilitate dynamics of sound co-creation and collective reflection, strengthening peer interaction and the social construction of musical knowledge.²⁶ Taken together, these experiences suggest that technology can

serve as a didactic mediator that expands spaces for artistic experimentation and communication, although its potential is conditioned by the design decisions and economic logics of the corporations that develop it.

Another significant finding in the reviewed literature is the growing emphasis on training in hybrid environments, which combine in-person and virtual settings as complementary spaces for musical learning. This hybridization is not merely a technical response to the limitations of in-person spaces: it is also a reconfiguration of pedagogical relationships, the teacher's role, and the forms of peer interaction. From ANT¹², hybrid environments can be analyzed as sociotechnical networks in which new actors videoconferencing platforms, shared-production tools, learning-management systems redistribute pedagogical agency and reconfigure the possibilities and limits of shared musical experience.

The literature also shows that processes of technological adoption in music education are neither linear nor homogeneous: they are mediated by professional teaching cultures, institutional histories, and the material conditions of each context. Studies conducted in Spanish-speaking contexts show that resistance to technological innovation in music education does not always stem from a lack of technical competence but frequently from a legitimate defense of the bodily and relational dimensions

of musical learning that teachers perceive as threatened by digitalization.³² This finding echoes earlier ecological accounts of technology adoption in schools, which showed that the uptake of digital tools by teachers depends on a dense web of interacting factors professional culture, perceived reliability, institutional support rather than on technical competence alone.³³ From the STS field, this resistance deserves to be taken seriously as a form of expert knowledge about the limits of technological mediation.

4.2. Active musical practice and bodily expression

The reviewed literature highlights the relevance of active musical practice, body percussion, collective singing, guided improvisation, and musical dance as pedagogical strategies that foster rhythmic development, motor coordination, active listening, and expressive creativity.^{6–8,24} The integration of bodily expression into music teaching reinforces the link between body, emotion, and sound, allowing learning to acquire an experiential and meaningful dimension.

From an STS perspective, the centrality of active practice and bodily expression emerges as a condition of possibility for musical learning that cannot be entirely mediated by technological artifacts. The body, in its variability, affectivity, and relationality, constitutes a form of knowledge-knowing-in-action, in Schön's sense³⁴, that

Table 1. Correlation between analytical categories, findings, and pedagogical prospects from a science and technology studies (STS) perspective

Analytical category	Main findings	Implications for teacher training	References
Integration of digital pedagogies (STS perspective)	Digital audio workstations and collaborative platforms promote creativity and co-creation, but operate within corporate ecosystems whose business logic shapes and constrains their pedagogical design. Platform discontinuation reveals the vulnerability of technological dependence.	Foster critical digital literacy; promote analysis of the sociotechnical conditions of tools; consider free or open-source software alternatives.	9,11,13,20
Generative artificial intelligence (GAI) in music education	GAI enables assisted composition and personalized learning, but raises questions about cultural biases in training data, intellectual property, and the privatization of musical knowledge.	Incorporate critical GAI literacy; address issues of authorship, rights, and cultural diversity; reflect on the political and economic conditions of GAI platforms.	2,16,17,25
Active musical practice and bodily expression	Body percussion, singing, improvisation, and dance strengthen active listening, coordination, and aesthetic sensitivity. Embodiment enhances musical experience and is irreducible to digital mediation.	Maintain active and bodily practice as the core of training, not as an optional complement; articulate the digital and the bodily as complementary dimensions of learning.	7,8,24,34
Development of critical teacher competences	Prospective teachers need interrelated digital, pedagogical-artistic, and sociotechnical-analysis competences. Continuing education should include reflection on the political and economic dimensions of technologies.	Redesign training programs with a competence-based, interdisciplinary, and STS-informed approach; incorporate critical platform analysis into digital teacher literacy.	5,12,32
Institutional challenges and digital sovereignty	Infrastructure limitations, resistance to change, and dependence on private platforms. The digital divide reflects structural inequalities, not merely technical shortcomings.	Implement digital-sovereignty policies; prioritize free and open-source software; develop teacher networks that include a critical, STS-informed dimension.	1,2,13,31

digital systems can complement but not replace. The reviewed literature converges on the view that the most effective pedagogical proposals are those that articulate, rather than oppose, the digital and bodily dimensions of musical learning.

4.3. Generative artificial intelligence and its sociotechnical implications in music education

Generative artificial intelligence represents the most recent and sociotechnically complex development in the landscape of musical educational technologies. The reviewed studies document its potential to support processes of assisted composition, interactive accompaniment, rhythm or pitch assessment, and the analysis of learning patterns.^{17,25} However, from an STS perspective, these uses raise questions that go beyond pedagogical effectiveness (Table 2).

First, the question of training data: musical GAI models are trained on corpora of music that reflect the inequalities of the global music market, with an over-representation of Western popular-music genres and traditions and an under-representation of world music, minority genres, and the musical practices of marginalized communities. This asymmetry in the training data translates into aesthetic and cultural biases in the generated compositions, which

has direct implications for the cultural diversity of music teacher training.

Second, the question of intellectual property and authorship: musical GAI systems generate content from copyrighted works without compensating their creators, which has generated ongoing legal and ethical controversies¹⁶, including active litigation over whether training generative systems on copyrighted musical works constitutes infringement or falls under fair use.³⁵ In the context of teacher training, this raises the need for legal and ethical literacy regarding the use of GAI, beyond mere technical proficiency.

Third, the political and economic dimension: the main musical GAI platforms are developed by private corporations with specific interests in monetizing the digital music market. Their adoption in public educational contexts reproduces the dynamics of knowledge privatization and technological dependence that warrant critical reflection from teacher-training institutions.

A fourth relevant aspect from an STS perspective is algorithmic transparency. Musical GAI systems operate as black boxes whose internal processes are opaque to most users, including teachers. This opacity is not technically

Table 2. Article search procedure in the literature review

Phase	Description	Details/examples	Purpose
1. Definition of objectives	Establishing the scope of the review	Identifying how digital pedagogies, active musical practice, and bodily expression influence teacher training, from a science and technology studies (STS) perspective	Guiding the search and selection of relevant literature
2. Source selection	Choosing databases	Scopus, Web of Science, ERIC, Google Scholar, Dialnet, Redalyc	Ensuring broad coverage and quality
3. Keywords	Terms and Boolean combinations	“Digital pedagogy,” “music education,” “STS education,” “social construction of technology,” “AI in education,” “platformization”	Maximizing relevance and thoroughness
4. Inclusion criteria	Documents considered	Publications 2010–2024, Spanish and English, teacher training, STS studies with educational connection	Filtering pertinent documents
5. Exclusion criteria	Documents excluded	Professional music education without pedagogical context; STS studies without educational connection; non-peer-reviewed publications	Avoiding irrelevant information
6. Data extraction	Collecting data	Author, year, type of study, methodology, findings, sociotechnical dimensions identified	Facilitating comparative analysis
7. Synthesis and analysis	Organizing findings from an STS perspective	Classification by axes: technological innovation, active practice, expressive mediations, sociotechnical dimensions, and political challenges	Identifying trends, gaps, and recommendations

inevitable: it is often a design decision intended to protect corporate intellectual property and hinder the replication or critique of the models. In the context of teacher training, teaching the use of GAI tools without reflecting on this algorithmic opacity reproduces an uncritical relationship with technology that the STS field has termed technological fetishism: the tendency to perceive technological artifacts as objects endowed with their own powers, independent of the social relations that produced them.²

Finally, it should be noted that the reviewed literature reveals an unresolved tension between pedagogical enthusiasm for GAI's possibilities and concern about its effects on the formative dimension of the creative process. Several studies indicate that the use of GAI systems to generate musical material may deprive students of the experience of progressively building their own compositional and interpretive abilities, replacing the formative process with an instantaneous result.¹⁷ This tension between productive efficiency and formative depth is, ultimately, a value tension that cannot be resolved through technical means: it requires pedagogical and ethical decisions that teacher-training programs should address explicitly.

4.4. Developing critical teacher and digital competences

The studies agree that music teacher training must encompass the acquisition of digital, pedagogical, and artistic competences that enable a critical, ethical, and reflective use of technology.^{5,21} From an STS perspective, this critical competence must include the capacity to analyze technologies in terms of their conditions of production, their business models, their implications for privacy and the sovereignty of educational data, and their effects on cultural diversity.

The literature also points to the need to strengthen continuing education and professional support through programs that integrate innovation, artistic practice, and critical digital literacy. In this sense, communities of teaching practice that include reflection on the sociotechnical dimensions of the tools they use represent a more robust formative model than mere technical training.³²

The concept of teacher digital competence has been operationalized in various reference frameworks, both at the European level (DigComp) and, specifically for teaching staff, the DigCompEdu framework³⁶, as well as in national adaptations. However, the literature review reveals that none of these frameworks systematically incorporates a sociotechnical dimension that extends beyond digital ethics and tool safety. STS competence understood as the

capacity to critically analyze technological artifacts from their conditions of production, their business models, their cultural implications, and their power relations remains virtually absent from the available frameworks of teacher digital competence, which represents a significant limitation for the training of critical teachers in the twenty-first century.

This absence is especially striking in the field of music training, where the adoption of specific technologies, notation systems, production software, and streaming platforms has historically shaped what music is considered legitimate, which practices are privileged, and what profiles of musician and teacher are formed. An STS history of music technology in education could reveal that tools are never neutral: from the grand piano to the synthesizer, and from the tape recorder to the DAW, each musical technology has redistributed musical agency, created new possibilities, closed off others, and reflected the economic and cultural conditions of its time.

4.5. Challenges and prospects: A sociotechnical reading

Despite theoretical and practical advances, various institutional and contextual challenges are identified. The lack of technological infrastructure, resistance to pedagogical change, and inequality in access to resources continue to limit the full implementation of digital pedagogies.^{1,31} From an STS reading, these challenges are not correctable technical anomalies that can be solved with more investment: they are expressions of the structural tensions that run through the relationship between public education systems and private technology markets.

The reviewed studies propose creating communities of teaching practice, support networks, and sustainable training programs that can overcome these barriers and consolidate a culture of critical educational innovation. Looking ahead, moving toward greater digital sovereignty in music education through the preferential use of free and open-source software, training in critical literacy about digital platforms, and the development of education policies that regulate data extraction in training environments emerges as a relevant agenda for the field.

The question of digital equity deserves special attention from the STS field. The digital divide in music education is not limited to inequality in access to devices and connectivity: it also includes what Selwyn⁹ calls the meaningful-use divide, that is, the difference between those who use technologies instrumentally and uncritically and those who do so reflectively, creatively, and with a capacity for critical appropriation. This second dimension of the digital divide is especially relevant in teacher-training

contexts, where what is at stake is not only the personal use of technology, but the capacity to design musical learning situations that are technologically rich and pedagogically meaningful for the full diversity of students.

From a gender perspective, the reviewed literature also indicates that the adoption of digital technologies in music education is not gender-neutral: studies show that digital music-production tools have historically been designed with an implicit male user in mind, and that gamification and electronic-production practices tend to reproduce gender biases in training environments.³⁷ Early STS-informed ethnographic work in secondary-school music technology classrooms similarly found that the equation of “composition” with the “music technology suite” was not gender-neutral, but reflected and reinforced the socially constructed association between computing and masculinity³⁸, a pattern consistent with broader feminist technoscience arguments that technologies are gendered both in their design and in their everyday use.³⁹ A critical music teacher training informed by an STS perspective must also incorporate this gender dimension into the analysis of the technologies it uses, with the aim of designing more inclusive and equitable formative experiences.

4.6. Synthesis of findings

Table 1 summarizes, in condensed form, how the five categories analyzed above relate to one another; each point is developed and discussed in depth in Section 5.

- Active musical practice and embodiment facilitate the experiential internalization of rhythmic and melodic concepts, strengthening the self-confidence and motivation of prospective teachers^{8,24}, and constitute a dimension of musical learning that no technology can replace.
- The pedagogical use of digital technologies and GAI fosters critical thinking, digital ethics, and reflection on creative authorship, provided it is accompanied by analytical frameworks that allow the sociotechnical conditions of these technologies to be problematized.^{17,26}
- The balanced articulation between technological innovation, active musical practice, and expressive mediations enhances methodological transfer to real primary-education contexts³², contributing to more resilient training programs that are consistent with the challenges of the 21st-century.

5. Discussion

The results of the literature review, analyzed from an STS perspective, indicate that the convergence of digital

pedagogies, active musical practice, and bodily expression constitutes a comprehensive training model that responds to the current challenges of music education in initial teacher training. However, this approach can be fully coherent only if it incorporates a critical reflection on the sociotechnical conditions of the technologies that mediate training.

5.1. Technology as pedagogical mediator and as sociotechnical artifact

The reviewed studies show that the use of digital platforms, virtual environments, and music-production tools fosters students' autonomy, motivation, and creativity.^{20,21} However, as argued in Section 2.1 with reference to Winner's² account of the politics of artifacts, digital technologies should be understood not only as a pedagogical medium but also as sociotechnical artifacts. Applied to the findings of this review, ignoring this dimension in teacher training amounts to preparing prospective teachers to use technologies without understanding them, limiting their capacity for critical appropriation and resistance to pedagogically inadequate uses.

In this sense, technology acquires value when it is oriented toward strengthening processes of sound experimentation, collective reflection, and expressive construction, but that value is conditioned by design decisions, access conditions, and the power relations that configure each specific technological artifact. 21st-century music teacher training therefore requires not only a pedagogy of technology but also a technology that is critically informed by pedagogy.

5.2. The centrality of the body and lived experience in musical learning

The review confirms that bodily expression and active practice constitute essential mediations in teacher training, enabling the experiential internalization of musical concepts and fostering connections among emotion, body, and sound.^{7,8} From an STS perspective, this centrality of the body has a political dimension: in the face of the tendency to digitalize every aspect of learning, insisting on active practice and bodily expression is also a way of resisting the reduction of musical learning to its computable and quantifiable dimensions.

Movement and embodiment bring a cognitive and emotional dimension that technology alone cannot reproduce. For this reason, the balanced integration of the digital and the bodily emerges as one of the keys to designing hybrid training environments that are coherent with the expressive nature of music and with the limits of technological mediation.

5.3. Generative artificial intelligence, authorship, and creativity: The debate from the field of science and technology studies

The emergence of GAI in music education raises one of the most relevant debates from an STS perspective: what does it mean to be creative when part of the creative process is delegated to an algorithmic system? This question is not merely philosophical: it has direct consequences for how music-training curricula are designed, how learning is assessed, and how the relationship between teacher, student, and technological tool is conceived.

Viewed through the ANT lens introduced in Section 2.1¹², GAI is not simply a tool but an actor within the sociotechnical network that redistributes creative agency, favoring certain types of music, styles, and production models depending on the data on which it was trained and the corporate interests that shape its development. Ignoring this dimension in teacher training amounts to naturalizing a distribution of creative agency that is, in fact, the result of human, economic, and political decisions.

This discussion connects with broader debates in the philosophy of technology and aesthetics regarding the distinctions among creativity and production, between originality and recombination, and between individual and distributed authorship. Far from being an abstract academic discussion, these debates have concrete curricular implications: how should a musical composition in which the student has used GAI to generate thematic material be assessed? What pedagogical criteria distinguish an educationally meaningful use of GAI from one that simply avoids formative effort? How can prospective teachers be trained to answer these questions in their own practice and in that of their primary-school students? The STS perspective does not provide definitive answers to these questions, but it does offer the conceptual tools to pose them rigorously and to situate them within their broader social, economic, and political coordinates.

5.4. Institutional challenges and digital sovereignty

Despite theoretical consensus on the potential of digital innovation, the reviewed literature points to persistent limitations related to a lack of technological infrastructure, unequal access, and institutional resistance to pedagogical change.^{31,32} From an STS perspective, these limitations are not merely technical or cultural obstacles: they are also expressions of the structural tensions between public education systems and private technology markets, between equity policies and dynamics of accumulation.

To overcome these barriers, studies propose creating communities of practice and teacher-support programs that foster collective reflection and ongoing professional

development. From an STS perspective, these communities should also have the capacity to analyze and question the platforms they use, to participate in debates on digital governance in education, and to contribute to the development of more sovereign and equitable alternatives.

5.5. Implications for twenty-first-century teacher training

Overall, the review shows the need to move toward a hybrid, inclusive, creative music education, critically informed by the STS field, in which technology and embodiment coexist as complementary dimensions of learning. This paradigm requires rethinking initial-training curricula, integrating active methodologies, interdisciplinary projects, sensory experiences, and critical reflection on the technologies used. 21st-century teachers will need to act not only as transmitters of knowledge or facilitators of artistic and digital experiences, but also as critical interpreters of the sociotechnical conditions that shape their practice.

This training model implies reconceptualizing the graduate profile in teacher-education curricula. If music teacher training has so far been organized around two axes—musical competences and pedagogical competences—the STS perspective proposes a third: sociotechnical competence. This competence refers to the capacity to critically analyze the technological artifacts that mediate musical education, understand the conditions under which they are produced and distributed, identify the values and interests they embody, and actively engage in debates on digital governance in education. This third axis does not replace the previous two: it completes them and situates them within a broader context that allows prospective teachers to act with greater autonomy, responsibility, and awareness in their professional practice.

From a curricular standpoint, this reconceptualization has concrete implications. Music-training modules should include not only instrumental practice, music theory, and didactics, but also critical analysis of musical technology platforms; case studies on the adoption and discontinuation of digital educational tools; ethical reflection on the use of GAI in composition and musical assessment; and discussion of digital-sovereignty policies in education. This curricular expansion does not necessarily require additional training minutes: it can be integrated transversally into existing activities, adding a reflective and critical dimension to the technological practices that students already engage in.

Finally, the STS perspective suggests that the transformation of music teacher training cannot depend exclusively on curricular changes driven by training institutions. It also requires changes to education policies that govern the use of private platforms in public

education, promote the development and adoption of open-source educational tools, and guarantee the protection of student data against commercial extraction by technology corporations. In this sense, the STS field contributes not only an analytical framework for understanding digital music education, but also a political agenda for transforming it in a more equitable, sovereign, and pedagogically meaningful direction.

6. Conclusion

This article has highlighted the contributions that digital pedagogies and educational innovation can offer to the musical training of prospective primary school teachers, especially when articulated with active musical practice and bodily expression as structuring axes of learning, and when problematized from an STS perspective.

The incorporation of technological tools DAWs, collaborative platforms, and GAI systems opens new possibilities for experimenting with, editing, sharing, and reflecting on sound processes from a creative and participatory perspective. However, this research reaffirms that musical training cannot be dissociated from its experiential and bodily dimension, nor can it ignore the sociotechnical conditions of the technologies that mediate it. The body remains the first instrument and the medium through which sound is embodied, understood, and communicated. Digital technologies from DAWs to GAI systems are not neutral instruments: they are artifacts whose values, interests, and operating logics deserve to be understood and questioned within the framework of teacher training.

The challenge does not lie solely in incorporating technology, but in rethinking the methodologies and pedagogical meanings that accompany it, and in developing in prospective teachers the capacity to critically analyze the sociotechnical conditions of the tools they use. Digital pedagogies must be conceived as means at the service of musical expression and understanding, but also as objects of critical reflection on the power, culture, and economics of educational technologies.

To strengthen initial teacher-training programs in music education, the following is recommended:

- Include specific music-technology modules with a practical, creative approach critically informed by the STS field, oriented toward sound production, pedagogical reflection, and analysis of the sociotechnical conditions of the tools used.
- Design hybrid experiences that combine digital resources and bodily practices, fostering the

connection between mind, body, and sound, without reducing musical learning to its computable dimensions.

- Incorporate into teacher digital literacy a critical dimension that addresses the political, economic, and cultural dimensions of the technological platforms used in training, including the implications of using GAI in educational contexts.
- Foster communities of teaching practice that share materials, methodologies, and experiences of educational musical innovation, and that include critical reflection on the sociotechnical conditions of their practice.
- Advance toward digital-sovereignty policies in music education that reduce dependence on private infrastructures and promote the use of open-source tools and the participation of educational institutions in the governance of the platforms they use

Finally, this work invites a rethinking of music teacher training as an integrative space where artistic sensitivity, digital literacy, and bodily awareness converge, alongside critical reflection on the sociotechnical conditions that shape 21st-century musical education. A truly comprehensive music teacher training cannot be limited to producing good users of technology: it must also form critical digital citizens, capable of understanding, questioning, and transforming the technological conditions in which they carry out their practice.

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