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Toward a meaningful technology for instrumental music education: Teachers' voice

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In musical instrument training, researchers have gradually started exploring the potential of interactive technologies supporting learning processes and teaching methods. Although numerous technological tools have been proposed to enhance instrument learning and teaching, these methods rarely find their way into daily practice and teaching routines. In this study, we report data from an online survey study administered to violin and drum kit teachers. Results reveal distinct learning profiles of novice violin and drum kit students and exhibit a variety of teaching approaches toward adults and children. Furthermore, they provide more insight into teachers' opinions on the use of virtual reality (VR) and smart wearable technologies in early instrumental training, as well as their attitudes regarding technology design. Overall, our findings highlight the importance of involving teachers in the initial stages of technology design to facilitate technology acceptance and adoption, prevent potential mismatches between requirements regarding technological functionality and actual user needs, and promote musical growth and skill acquisition.

KEYWORDS

music education, musical instrument training, technology, learning, virtual reality, wearable device, teaching approach, technology acceptance

Introduction

Learning to play a musical instrument consists of an intensive process entailing skill acquisition as well as instrumental, technical, conceptual and artistic development (Ericsson, 1997, 2003). Over years of practice, learners develop goal-oriented and self-regulatory practice strategies (Platz et al., 2014; Hallam et al., 2018) to master precise spatiotemporal control of limb coordination (Schoonderwaldt and Demoucron, 2009;

Mutio et al., 2017) and acquire the freedom to express themselves musically (Ericsson, 1997, 2003). It requires a substantial amount of self-determination, discipline and motivation from students to stay engaged in music practice in the long term (Upitis et al., 2017; Colwell et al., 2018). Nevertheless, learning to play an instrument is rarely a solitary endeavor, as it is embedded in dynamic social networks/contexts where interactions with teachers, caregivers and peers have the power to shape one's teaching and learning experience (Creech and Hallam, 2011, 2017; Nielsen and Johansen, 2021; Zdzinski, 2021).

Therefore, during music training, students usually follow regular one-to-one classes with a qualified teacher, followed by periods of self-study (Creech and Gaunt, 2012; Gaunt et al., 2021). During these courses, teachers tend to adapt their teaching strategies according to specific aspects of the student's profile (e.g., age, years of experience, cognitive and motor abilities), learning goals (e.g., learning a tune, specific sound effect and technique) or the studio environment (Bauer, 2020; Schiavio et al., 2020). These strategies are often based on a master-apprentice model (Folkestad, 2006; Calvert, 2014; Schiavio et al., 2020). Despite key achievements (e.g., high music performance standards, rich repertoire and extensive instructional material), this educational approach is also prone to critique in the light of recent pedagogical insights. Studies have shown that the master-apprentice model is often characterized by a teacher-centered approach with a focus on technique in order to support reproductive imitation, corrected mainly by verbal feedback, aural modeling and physical guidance (see McPherson and Welch, 2012; Daniel and Parkes, 2015). A potentially problematic aspect of such conventional ways of teaching is their proneness to ambiguous interpretation and delayed feedback (Welch et al., 2005; Hoppe et al., 2006; Howard et al., 2007). Welch et al. (2005) describe the traditional instrumental or singing lesson as a process where the teacher produces a prototypical performance, which is followed by the student's attempt to replicate the performance. Subsequently, the teacher evaluates the student's performance, after which he/she tries to improve his/her performance based on the provided feedback. A potential pitfall of this procedure is identified by Welch et al. (2005), Howard et al. (2007), referring to a dual misinterpretation of information. For instance, on the one hand, by describing musical gestures through speech, a teacher might fail to accurately describe the student's performance, while on the other, the student, who subsequently aims to translate the administered verbal and visual feedback into an adapted performance, may fail to correctly interpret the teacher's cues (Welch et al., 2005; Howard et al., 2007). Indeed, verbal instruction, physical guidance and movement imitation provide at best a rough approximation of the target movement and may easily lead to misinterpretation (Grindlay, 2008; van der Linden et al., 2010), especially when we also consider that every teacher uses his/her idiosyncratic pedagogic vocabulary while teaching (Howard et al., 2007). Another drawback of this way of working is delayed feedback, as the evaluation of the performance is often provided *a posteriori* (Welch, 1985; Welch et al., 1989). As a result, the critical learning period is mainly distributed over two points in time, i.e., the *post hoc* feedback stage and the performative response (Hoppe et al., 2006).

An increasingly popular way to deal with such issues involves the use of digital monitoring applications, using sensing technologies such as *motion capture* (e.g., Volta and Volpe, 2019; D'Amato et al., 2020), *optical sensors* (e.g., Pardue, 2017; Provenzale et al., 2021), *infrared depth camera* (e.g., Vamvakousis et al., 2018) and *audio information retrieval techniques* (e.g., Schoonderwaldt and Demoucron, 2009; Perez Carrillo and Wanderley, 2012). These digital monitoring applications instantly process players' movement patterns and provide them with immediate feedback on, for instance, errors regarding posture, sound quality, melody or rhythm (Blanco et al., 2021; Bobbe et al., 2021). Indeed, the advent of such technologies inspired a growing belief in the potential of technological tools to enhance teaching and learning quality and spur further educational developments (Savage, 2007). New technologies are assumed to help overcome the above-mentioned limitations of the traditional master-apprentice approach (Grindlay, 2008; van der Linden et al., 2009). For example, wearables (i.e., any kind of electronic device designed to be worn on the user's body) may complement, or even supersede, the appraisal of the teacher by providing more objective, and thus less ambiguous, feedback in real-time (vs. *a posteriori*) based on the quantification of sound and movement (Blanco et al., 2021). Examples of such applications are, for instance: *MusicJacket*, a wearable system that tracks the movements of the player and provides vibrotactile feedback whenever he/she deviates from a target trajectory (van der Linden et al., 2011); *Haptic Guidance System apparatus* (HAGUS), which targets the ideal rendition of wrist movements while drumming (Grindlay, 2008); *HapTune*, a system for string instruments providing vibrotactile feedback to support pitch note playing (Yoo and Choi, 2017); and *POSTRUM*, a wearable system for trumpet players applying real-time haptic feedback to improve posture (Dalgleish and Spencer, 2014).

One of the most recent technological developments regarding music training is the introduction of Virtual Reality (VR). For instance, *Virtual Reality Exposure Training for Musicians* is a VR application developed to tackle performance anxiety (Bissonnette et al., 2015), while *DrumBeats VR* (Eissens and VRROOM Ultimate VR Experiences BV, 2019), *Garage Drummer VR* (Blazing Tree Studio, 2016) and *Paradiddle* (Tanirgan, 2017) are commercially available drumming apps, simulating different drum kit setups and environments, and supporting the transfer of newly acquired skills to a real drum kit.

Notwithstanding the potential of such applications, so far, they rarely seem to find their way into daily study practices and didactic strategies (Bobbe et al., 2021). This adoption gap has been associated with several factors. According to Mroziak and Bowman (2016), teachers are often not trained to use these technologies. This lack of training and experience with regard to technology use was especially noticeable during the lockdown prompted by the COVID-19 pandemic, which forced music instrument tutors to teach remotely and adjust their typical training strategies to entirely new contexts (Calderón-Garrido et al., 2019; De Bruin, 2021; Onderdijk et al., 2021; Schiavio et al., 2021). Bauer (2014) argues that it is not sufficient to show teachers how technology works, rather, they should be made aware of the affordances these technologies might have for their further teaching careers. Therefore, he proposed the *Technological, Pedagogical and Content Knowledge framework* (TPACK) that considers how technological, pedagogical and content knowledge dynamically interact, creating a knowledge intersection (Bauer, 2014; Hilton, 2016). Together with another methodological tool, the *Substitution Augmentation Modification Redefinition* (SAMR) model, TPACK might allow educators to discover how to optimally integrate technology in the studio in order to improve instruction (Puentedura, 2013; Hilton, 2016).

Another potential argument for the adoption gap refers to the general dominance of technology-driven approaches, rather than those steered by pedagogical considerations (Revelle, 2013; Leman and Nijs, 2017; Bobbe et al., 2021). For instance, the aforementioned commercially available VR applications for the drum kit generally lack physical rebound, a critical feature for mastering highly accurate motor patterns (West, 2021). As a consequence, students could pick up erroneous movement patterns when using such apps. Arguably, the overall inadequacy to sufficiently meet pedagogical requirements could be related to the fact that end-user involvement commonly only occurs at the later stages of the technology development cycle (van der Linden et al., 2011; Bobbe et al., 2021). Moreover, social dynamics of the learning and teaching context are often not considered.

Research on motivation and dropout prevention in music education suggests that parental support as well as the relationship between the teacher, caregivers and child are pivotal to engage students in regular and long-term music practice (Davidson et al., 1996; Zdzinski, 2021). For instance, assistance and positive reinforcement from teachers and caregivers have been shown to boost students' engagement with their instruments and to significantly impact learning outcomes (Creech and Hallam, 2011, Goodway et al., 2019; Zdzinski, 2021). Nevertheless, many of the educational applications for novice students (who may be minors or adults) are developed to be used during a self-study period, even though the students do not have appropriate schemata to evaluate their progress and assess their errors (McPherson and Renwick, 2001; Hallam et al., 2012). At the same time, applications providing feedback during a self-study period might hinder the development of students' self-efficacy–a powerful factor for predicting long-term engagement in music training–as students might rely too extensively on the monitoring functions of the device (Upitis et al., 2017; Krause and Davidson, 2018). Moreover, many of these educational applications implement visual feedback (Welch et al., 2005; Blanco et al., 2021). Callaghan et al. (2004), Wilson et al. (2005) suggest that visual feedback is often hard to interpret for novices, possibly due to an overabundance of provided information. Hence, the tutor's guidance is key, especially for novice students, as it reinforces learning strategy advancements, supporting developments in aural, cognitive, motor, technical and musical communication and performing skills (Creech, 2012). Furthermore, previous work on technology adoption suggests that especially teachers' assessments of the usefulness of the technology, their attitudes toward its use and their technological self-efficacy directly impact their overall willingness to employ the tool, while perceived ease of use, technological complexity and facilitating conditions are shown to generate more indirect effects (Teo, 2009; Teo and Bahçekapili, 2012). Considering the above, it is rather surprising that teachers are often not fully involved from the earliest stages of technology development.

In our view, to achieve successful technology adoption, a participatory design should be implemented, encompassing intense interaction between developers and educators from the very beginning of product development. This idea is in line with the concept of user-centered design, where, rather than the functionalities of the technology itself, the needs of its prospective users are taken as a starting point (Revelle, 2013; Bobbe et al., 2021). In instrumental music training, such requirements may involve awareness of developmental needs, abilities and challenges of students in various age groups; an understanding of training strategies, needs and challenges of teachers; as well as an understanding of the interaction dynamics between students, caregivers and teachers. Hence, this study aims to obtain a more elaborate understanding of music teachers' attitudes toward technology adaptation, potentially fueling further developments in technology design and implementation for music training.

This study is part of a larger project, CONnected through ROBotS (CONBOTS), which focuses on the development of an innovative modular robotic platform facilitating musical instrument training. By implementing bi-directional haptic communication between two users (human-human or human-robot) and AR/VR-based applications, the platform aims to improve the efficiency of the training in order to enhance sensorimotor skill acquisition of novice violin and drum kit students. As this bears upon the core of musical instrument teaching and learning, we aim to position teachers at the very center of the discourse. Using an online survey administered to violin and drum kit teachers, we examined the profiles of violin and drum kit students and teachers. We collected teachers' descriptions of typical learning challenges encountered while training novice students. We also examined their opinions toward the use of technology in the studio and ideas regarding technology design. Overall, by exploring key aspects of music training as well as physical and cognitive features of user profiles, suggestions are provided for developers and other stakeholders on how to more optimally meet the needs of the foreseen end-users of technological tools and applications for musical instrument training. An improved understanding of these matters could support the prevention of potential mismatches between requirements regarding technological functionality and actual user needs. Moreover, it could facilitate technology acceptance and adoption as well as promote students' skill acquisition and musical growth.

Materials and methods

Survey design

The design of survey items was based on exploratory interviews with two violin teachers, two drum kit teachers and two technology developers, which were further revised by experts in music education, musicology and technology development. The survey (see **Supplementary material**) included multiple-choice questions, open-ended questions and Likert scales. It also included a written description of the terms "VR technology" and "wearable devices for postural support." We used a mixed-methods approach in order to investigate learning profiles of novice violin and drum kit students, teachers' descriptions of typical learning challenges encountered while teaching novice students, and their opinions toward the use of technology in the studio. The survey consisted of the following sections and content:

General information: demographics; overall teaching experience.

Violin/drum kit teaching experience: beginner students' profiles; differences between adult and child beginners; teaching materials and first lesson scenarios; use of wearables/postural support; attitudes toward postural support devices; suggestions for teaching device design.

Virtual reality experience: previous VR experience; current VR knowledge; views on the application of VR in music education.

Data collection

Data were collected using an online survey administered in Microsoft Forms and distributed from 26 November 2020 until 5 January 2021. Violin and drum kit teachers from different countries were recruited using purposive sampling (Williamon et al., 2021), in order to capture a diverse cross-section of teaching methods, music education systems, and to compensate for potential gender imbalances. Teaching strategies between violin and drum kit tutors might vary substantially as the violin is predominantly associated with a more classical music repertoire, whereas the drum kit is commonly associated with more modern and improvised music, involving specific styles such as jazz, pop and rock (Zhu et al., 2004; Brennan, 2021). Moreover, violin pedagogy started to be systematized and well documented from the eighteenth century onwards (see Mozart, 1756; Baillot and Kreutzer, 1802; Spohr, 1832; Auer, 1921), whereas drum kit training is largely excluded as a requirement in the collegiate percussion studio (Pickering, 2020; Smith and Davis, 2022). Also, music education systems are found to vary substantially between countries in terms of the intensity of weekly individual instrument and ensemble lessons (Hofstede, 1983, 2011). Furthermore, regardless of musical style, significantly more females were shown to play the violin, while drummers were more often of the male gender (Harrison and O'Neill, 2000; Suki, 2011; Wrape et al., 2016).

Teachers were recruited through a range of online channels, such as mailing lists, music school websites and targeted social media. Participation was voluntary and respondents were informed about the goal of the survey in the preface of the questionnaire. All responses were anonymous, participants could not be identified from the material and all procedures were approved by the ethical committee of the authors' institution. Only one submission per participant was allowed. Respondents were able to fill out the survey in Dutch, Polish or English and were informed that it would take approximately 20 mins to complete. Only fully completed surveys were considered and no financial compensation was provided. In total, $N = 73$ valid responses were recorded.

Data analysis

Data were preprocessed using Microsoft Excel. Dutch and Polish responses were translated to English. R version 4.0.2 (R Core Team, 2020) for data analysis. All functions used were part of the base R environment. Descriptive analysis of violin and drum teachers' profiles as well as thematic analysis of open questions were performed (Braun and Clarke, 2012). The latter was performed by two researchers and was based on four predefined themes derived from existing knowledge and literature, i.e., (1) *differences between adult and child students*, (2) *challenges encountered while tutoring child novice students*, (3) *challenges encountered while tutoring adult novice students*, and (4) *teachers' attitudes toward the use of wearable devices and VR in music training.* The thematic analysis was performed as follows: one researcher analyzed and categorized the answers of the violin teachers while the other analyzed and categorized the responses of the drum kit teachers. Subsequently, researchers switched roles. The process was repeated until no further themes and categories could be interpreted from the data. As a result, a new theme emerged, i.e., (5) *differences in communication and*

TABLE 1 Teachers' demographics.

	Total $N = 73$ (100%)	Drum kit teachers $n = 32$ (43.8%)	Violin teachers $n = 41$ (56.2%)
Survey filled in . . . language			
Dutch	48 (65.8%)	22 (68.8%)	26 (63.4%)
English	11 (15.1%)	6 (18.8%)	5 (12.2%)
Polish	14 (19.2%)	4 (12.5%)	10 (24.4%)
Age			
18–25	2 (2.7%)	2 (6.3%)	–
26–35	16 (21.9%)	7 (21.9%)	9 (22%)
46–55	16 (21.9%)	5 (15.6%)	11 (26.8%)
36–45	24 (32.9%)	12 (37.5%)	12 (29.3%)
55<	15 (20.6%)	6 (18.8%)	9 (22%)
Hours of weekly tutoring			
5>	4 (5.5%)	1 (3.1%)	3 (7.3%)
5–9	6 (8.2%)	5 (15.6%)	1 (2.4%)
10–14	11 (15.1%)	5 (15.6%)	6 (14.6%)
15–19	17 (23.3%)	8 (25%)	9 (22%)
20<	35 (48%)	13 (40.6%)	22 (53.7%)
Years of experience			
0–3	2 (2.7%)	2 (6.3%)	–
4–7	8 (11%)	4 (12.5%)	4 (9.8%)
8–10	6 (8.2%)	4 (12.5%)	2 (4.9%)
11–20	26 (35.6%)	11 (34.4%)	15 (36.6%)
21–30	21 (28.8%)	8 (25%)	13 (31.7%)
31–40	10 (13.7%)	3 (9.4%)	7 (17.1%)
Student age categories			
Children			
Yes	70 (95.9%)	29 (90.6%)	41 (100%)
No	3 (4.1%)	3 (9.4%)	–
Adults			
Yes	46 (63%)	22 (68.8%)	24 (58.5%)
No	27 (37%)	10 (31.3%)	17 (41.5%)
VR use			
Yes	15 (20.6%)	8 (25%)	7 (17.1%)
No	58 (79.5%)	24 (75%)	34 (82.9%)

learning strategies between adults and children, in addition to the four predefined themes.

Results

Demographics

In total, $N = 73$ valid responses were recorded of which 43.8% ($n = 32$) of all respondents taught drum kit and 56.2% ($n = 41$) the violin. The majority filled out the survey in Dutch (65.8%, $n = 48$), 19.2% ($n = 14$) in Polish and 15.1% in English ($n = 11$). Forty-five percent ($n = 33$) were female, 52.1% ($n = 38$) were male and 2.7% ($n = 2$) preferred not to disclose. The gender distribution strongly differed between violinists and drummers (see **Table 1**), reflecting previously reported gender imbalances regarding instrument selection (Harrison and O'Neill, 2000; Suki, 2011; Wrape et al., 2016). See **Table 1** for a detailed overview.

Student profiles

Cognitive and motor differences between children and adults

The teachers in this study observed differences between novice adults and children, mainly regarding cognitive (e.g., conceptual understanding and awareness) and motor abilities (e.g., movement automation).

According to 31.3% ($n = 10$) of drum kit teachers and 29.3% ($n = 12$) of violin teachers, adults grasp concepts and objectives quicker than children. The data highlighted that, when compared to children, teachers find explaining lesson content to adults easier, as adults tend to have more musical experience and cognitive capacity. Moreover, 28.1% ($n = 9$) of drum kit teachers indicated that adults are generally more focused and display a higher understanding of the importance of working on instrumental technique. Respondents D28[1] and V43 reported that children need more guidance during the teaching process as they tend to forget the instructions more easily and are often not all too concerned with technical aspects:

> "The start is faster with an adult because he/she follows the instructions better. The child responds better to examples and repetition. A child needs more constant guidance in this regard." (D28)

> "Children repeat much more without analyzing how to do it, adults look for a scheme of action, try to control a lot with their minds. Children remember the melody with their fingers, adults remember it by recalling the notes." (V43)

Of all respondents, 12.3% ($n = 9$) stated that adults have higher self-awareness and can work more autonomously on technique than children. However, as respondent V63 noted, adults ask a lot of questions and commonly better understand how things need to be done, but at the same time are often hindered by this understanding:

1 Quotes of teachers are indicated with the letter "D" for drum kit teachers, and "V" for violin teachers, followed by the corresponding identification number from the dataset, e.g., D28 and V43.

> "[. . .] An adult can usually understand better how it has to be done, but strangely enough is often hindered by this. For example, placing a second finger high or low, learning vibrato (first large sliding movement)." (V63)

In regard to motor skill acquisition, 26% (*n* = 19) of teachers stated that adult novices often tend to overthink and overanalyze their movements, whereas children imitate them more immediately/intuitively and as a result tend to move more naturally:

> "Child: will do the movement much more naturally, because they work more intuitively. Adult: wants to have control over what he/she does and will try to think more about motor skills. As a result, the movements are sometimes less natural and stiffer." (D29)

> "[. . .] The adult pupil understands better what the motor movement should be but often cannot work it out properly immediately. A child thinks less about what he/she is doing but is flexible in executing motor movements." (V60)

The fact that *"the adult understands things sometimes 'too' quickly and therefore cannot follow with his motor skills"* (D68) might produce feelings of frustration and make the adult discontinue the practice:

> "Adult students get frustrated faster and will give up." (D09)

> "An adult is more likely to panic if something does not work from the first time, performance anxiety is [also] much more evident [than with children]. They also give up more quickly than children. Children try and do. If they fail, they can become nervous or annoyed but they try again and if they succeed, they forget their frustration immediately." (D24)

> "Playing the violin requires a lot of automation of movements. Because adults do understand, but the processes are not yet automated, they will feel more frustrated regarding the result after a few years." (V65)

Even though children appear to assimilate conceptual instructions slower than adults, it could be that some young students attain better motor control more quickly than adults. As this violin teacher mentioned:

> "As adults can analyze better (error analysis) they will make faster progress in the first lessons than a small child. [. . .] Playing the violin requires a lot of automation of movements. [. . .] Automation [with adult people] is also less efficient than with young people, which means that after a few years there is a turning point where children progress faster than adults." (V65)

Furthermore, 39.7% (*n* = 29) of teachers reported adults to be less flexible and have stiffer joints than children, whereas 20.6% (*n* = 15) identified that children adopt correct posture and motor skills more swiftly than adults, e.g.:

> "Children generally improve motor skills faster [than adults]. You need to give more time to an adult to master the motor skills. [. . .]" (D31)

Three respondents reported somewhat different observations. Respondents D26 and D12, for example, were more nuanced in their answers and indicated that efficient motor skill acquisition is connected to the student's level of attention and deliberate practice rather than to age.

> "If children pick it up correctly, they can automatize it quicker/faster." (D26)

> "Motor aspects depend little on age (unless younger than six and older than . . . it depends on the health state). However, it is more the intention/regularity that is decisive. For instance, the drumstick grip in young people is more 'natural' than in adult learners. Grip improvement depends on the 'specific attention' during practice but is certainly achievable for all age groups [. . .]." (D12)

Encountered challenges: Child novices

Thematic analyses of the second theme, *challenges encountered by teachers while teaching child beginner students,* suggest that violin and drum kit teachers experience similar problems while teaching young novices. The four main challenges that arose were: (1) acquisition of correct posture (mentioned fourteen times), (2) lack of concentration (mentioned twelve times), (3) lack of regular and correct practice at home (mentioned twelve times), and (4) difficulty to understand music notation and rhythmic values (mentioned seven times). To tackle these challenges, teachers proposed different solutions. For instance, for the acquisition of correct posture, they recommended general developmental exercises together with asserting the importance and potential long-term negative effects of neglecting postural recommendations. To compensate for lack of concentration, some provide more variable exercises, reward students with stickers/practice cards or try to increase parental involvement. Moreover, 19.5% (*n*

= 8) of violin teachers and 12.5% (n = 4) of drum kit teachers emphasized the importance of parental support in the learning process:

> "Help from the home environment is important for young children. Hence, the parent comes to class. If the parent guides the child properly, I experience little problems. [. . .]" (V52)

> "A child does not always manage to perform exercises correctly. Adjustment is done gradually. [. . .] It helps when parents join the lesson and can then guide the child during the practice at home." (D28)

Two violin participants explicitly indicated that contact with the parents could also entail some challenges:

> "The main problem among young novices is the lack of proper exercise at home, which is most often a flaw of the parents who do not want to cooperate with the teacher and believe that the child will do it by him/herself. [. . .]" (V41)

Besides the aforementioned challenges, some teachers touched upon more specific issues. For instance, drum kit teachers referred to the absence of ensemble experience (mentioned three times) as a challenge for young novices. Violin teachers pointed out that young novices tend to have underdeveloped motor control and weaker muscles (mentioned nine times), besides struggling with intonation (mentioned three times). For an overview of all challenges and possible solutions, see **Table 2**.

Encountered challenges: Adult novices

Thematic analyses of the third theme, i.e., *challenges encountered by teachers while teaching adult beginner students,* revealed four main challenges encountered by violin and drum kit teachers while teaching adult beginners: (1) acquisition of motor skills and coordination, and lack of mobility of the joints (mentioned eighteen times); (2) impatience (mentioned twelve times); (3) lack of regular practice at home (mentioned eight times); and (4) tendency to overanalyze instruction (mentioned eight times). In addition, violin teachers also reported on students' experienced feelings of tension (mentioned six times).

Teachers recommended various solutions to overcome these challenges. For instance, they proposed to perform exercises promoting limb coordination and independence or to use backing tracks to overcome the first challenge. To deal with impatience, they advised tailoring the repertoire to the individual's motor capabilities, facilitating maximum playing pleasure and avoiding further tension. To reduce students' tendencies to overanalyze exercises and movement execution, teachers advocate using conversation in order to calm the students down or try to redirect their focus. For an overview of all disclosed challenges and potential solutions, see **Table 2**.

Communication and teaching strategies

This theme emerged from the teachers' accounts of the other themes. To secure optimal knowledge transfer, both drum kit and violin teachers seem to, consciously and systematically, adjust their communication strategies according to the age of the students, with the aim to secure optimal knowledge transfer:

> "I sell/wrap the technique differently: the same techniques are taught, but other types of exercises, methods, . . . are used. For instance, commencing coordination exercises: I make them more playful for young novices [compared to adults], with games and pre- and post-performance exercises. With adults, I will start with notes much faster than with children." (D27)

When teaching adults, verbal instructions seem to prevail. Respondents adopt specialist terminology, for instance using particular muscle and joint names, and often describe movement sequences in detail. When tutoring children, however, they mainly use metaphors and analogies with daily activities:

> "Adult: I can refer to the joints and muscles they should use. Where they certainly should not feel/cause tension. Child: I use more simple ideas like 'hit with a hammer,' 'big and small movement,' 'bounce the basketball.'" (D29)

> "A beginner, child or adult, needs steps, but with a child, you have to allocate more time per step and explain the steps more metaphorically, while with adults you can use more 'standard' language." (V64)

When teaching children, shorter verbal explanations are employed, and performance is guided using movement demonstrations, physical cues and games:

> "With children, you are more likely to hold an arm or hand to guide the movement; with adults you are more likely to explain what to do using words." (V54)

> "With an adult student, you can illustrate the technique and provide some explanation about it. For a child, the explanation is shorter, and the focus is more on the different steps that are necessary to be able to execute a certain movement. [. . .]" (D60)

Teachers also tend to *"limit the explanation to one movement and then practice it playfully"* (V61) for children, whereas for adults they "*can usually give several points of attention as they are cognitively more developed.*" (D15). Respondent D32 remarked that the same resources could be employed for adult and child novices:

> "With an adult, you can describe a movement and have intermediate steps performed. With a child, you try to start

TABLE 2 Teachers' reported challenges and solutions.

Challenges (mentioned . . . times)	Suggested solutions	Illustrative quotes
Adult novices		
Acquisition of motor skills, coordination, and lack of joint mobility (18)	• Provide a variety of exercises for limb coordination and independence as well as stretching exercises without the use of an instrument, mostly to loosen the grip • Encourage students to do sports and use backing tracks • Adjust the repertoire to the motor possibilities of the student so that maximum playing pleasure is achieved and further tension avoided	'[...] Adults are stiff, it is difficult to adjust the developed bones and muscles to an unusual posture that you need for a violin." (V41) "Coordination can often be poor, also trying to run before they can walk. Engaging material and backing tracks straight away." (D05)
Impatience (12)	• Offer students musical content in a different form, for example, watching videos of violinists, listening to, and discussing music. This way students are engaged with the violin and motivated to keep on practicing until the technique is sufficiently mastered • Select enjoyable and varied exercises that are musically interesting and engaging, and on the student's current level of motor skill • Incorporate relaxation exercises	"[. . .] Adults are easily frustrated when something doesn't work as well as they thought it would. Here, the emphasis is also on being calm and relaxed. The same relaxation exercises can help." (V60) "Adults are more likely to come to class with a clear goal. [. . .] To achieve this, a lot of technique and coordination exercises are often required, which at first sight have nothing to do with these pieces. That is why adults can often focus too hard on a specific goal without wanting to work gradually toward it." (D22)
Lack of regular practice at home (8)	• Draw/make a training schedule • Select enjoyable and varied exercises that are musically interesting and engaging, and on the student's current level of motor skill	"Technical problems resulting from aging and lack of individual work. Percussion is often treated by them as a relaxing activity, occurring once a week." (D01) "I think that needing to practice a lot can be frustrating for fully formed adults, who aren't spending much of their days 'practicing' anything anymore. So, motivating adult students to keep practicing is sometimes hard when they want to be able to simply 'get it.'" (V46)
Tendency to overanalyze (8)	• Encourage students not too overanalyze every movement through conversation • Redirect focus of a student away from movement, e.g., making the student execute repetitive movements with different types of music • Ask students to just watch, listen and imitate	"Adults want to understand and grasp a lot at the same time, while the first building blocks require a lot of time to absorb the motor skills. Practicing the first movements very repetitively with different types of music/exercises/assignments is great for adults, in order to make them think less and do more instead." (D29) "Questioning or analyzing aspects of violin playing too deeply sometimes stands in the way of acquiring new skills. [. . .]" (V48)
Adult novices: violin only		
Being tense (6)	• Offer relaxation exercises, for example exercises from the book 'Basics' by S. Fisher	"You can get rid of tension through relaxation exercises without an instrument, by making them aware of incorrect postures, by talking to them (also about other things than the instrument lesson), by explaining what happens if they show a certain tension in certain muscles and how they can counteract that." (V59) "This is usually about 'relaxing while you play'. This can be particularly difficult in the beginning. Learning to use the bow in a relaxed manner is very difficult. There are a lot of exercises for this in the book 'Basics' by S. Fisher." (V54)
Young novices		
Acquisition of correct posture (14)	• Consistently explain and demonstrate correct stick grip and posture • Make a video of a student so that he/she can self-evaluate and see his/her mistake • Use general developmental exercises together with explaining its importance and potential long-term negative effects of incorrect posture	"[.] Poor posture–I use again general developmental exercises, but also explain to children about the spine and possible long-term effects of neglecting the correct posture." (V36) "Learning correct posture and fixing posture/body position, as well as stick grip." (D02)
Lack of concentration (12)	• Provide highly variable exercises during the lesson • Clarify that jokes are allowed, but that learning how to play an instrument also entails systematic practice and determination/persistence Introduce sufficient short breaks • Alternate between exercises • Insert game elements • React to students' input, i.e., provide immediate responses to their questions, let them talk about their day	"Lack of concentration, lack of individual work at home. The solution could be a high variability in exercises and lessons, not to focus on only one issue during the entire lesson. [.]" (Drum teacher, P01) "The challenges have to do with concentration and learning to be aware of the relevance of a good posture. Fortunately, you can tackle a lot physically, by dancing and singing, and walking and jumping." (V50)

(Continued)

TABLE 2 (Continued)

Challenges (mentioned . . . times)	Suggested solutions	Illustrative quotes
Lack of regular and correct practice at home (12)	• Motivate students by selecting customized material/music for each individual student • Involve parents in the practice of students, e.g., invite them to attend lessons, recall remarks and point out mistakes • Grade the length of the workload at home • Reward students with stickers or practice card • Organize regular class concerts of up to 15 mins	"The biggest 'problem' is that children more frequently come to class unprepared. They also do not like to do the same exercise week after week, but sometimes this cannot be done differently, for instance when the child did not practice. The task of the teacher is then to give a so-called different exercise that ultimately serves the same purpose, without the child realizing/feeling that he is stack with the same 'issue."' (D22) "[Challenge with] self-control in young children while practicing at home. Solution: parents' help (parents attend violin lessons), recalling the teacher's remarks and pointing out mistakes." (V33)
Understanding music notation and rhythmic values (7)	• Use counting games • Simplify concepts using metaphors • Play before and after the child with references to music scores • Play along with the student • Let the student play with recordings Focus on recognizability and enjoyment principles	"Music notation is often too abstract. Therefore, showing how to play before and after child's turn with reference to score [helps]." (D13) "The very beginning of solfège often goes slow. They often play more advanced pieces on their instrument than what they already know from solfège. It is thus more listening and playing after the teacher than reading, so more intuitive, which has advantages and disadvantages. Enjoyability, recognizability and ability to play along with the teacher and/or recordings is more crucial than for adults." (V48)
Young novices: drum kit		
Keeping up steady tempo (3)	• Use backing tracks • Accompany student on another instrument • Make a child count out loud, as this leads to a better feeling of the pulse	"[. . .] Tempo stability is also a major problem. Solution: making the child count out loud leads to a better metronome feeling." (D31) "Some children don't feel a pulse. Solution: a lot of clapping with the music and counting out loud." (D26)
No experience in playing with the group (3)	• Use backing tracks • Accompany student on another instrument	"Knowing where you are musically, without having much experience in band practice, or other musical frames of mind, is always a problem. This could be solved with backing tracks that are song specific." (D07) "Not knowing how something should sound creates a disadvantage. Solution: lots of pre-playing and listening to the recordings can help with this" (D31)
Young novices: violin		
Underdeveloped motor control and weak muscle (9)	• Use developmental and targeted exercises to improve motor control and strengthen muscles (mainly focusing on strengthening fingers, hands and shoulder girdle) • Demonstrate slow and steady exercises without bow or violin to control specific parts of the body, e.g., demonstrate enlarged arm movements • Use games such as tapping macrobeats by foot and clapping microbeats, while singing or playing a song	"Muscle Isolation – Exercises to control specific body parts. Weak muscles – general developmental and targeted exercises (mainly strengthening fingers, hands and shoulder girdle). Poor posture – I use again general developmental exercises, but also explain to children the functioning of the spine and possible long-term effects of neglecting the correct posture." (V36) "Underdeveloped motor control – slow and steady approach necessary. Basic physical movements, for example larger arm movements, which are refined over time. [. . .]" (V47)
Intonation (3)	• Introduce individual elements of playing technique one by one and consolidate them through exercises • Encourage a student to sing or imagine the sound before playing • Let the student listen to the recorded performance, invite her/him to discover where in her/his opinion the intonation was either good or not • In group sessions, let the children play the evaluation game all together, in a sort of peer tutoring, with each child helping the peer to solve the problem	"Intonation on violin is a challenge. I encourage the student to sing and, subsequently, to imagine the sound before playing. Frequently, we listen the recorded performance again and I invite the child to discover where in its opinion the intonation was good or not. [. . .]" (V45) "[. . .] Control over several elements, e.g., intonation and simple bow guidance; you have to introduce individual elements of the playing technique one by one and consolidate them through exercises" (V39)

from parallels with evident movements from daily life: with a downward and upward movement on the hi-hat, or for accents on a drum, you can start from dribbling or throwing and catching a ball. You make them aware of the movement of their arm-wrist-hand. You can of course also use these resources for adults. [. . .]" (D32)

To reduce adults' levels of self-evaluation and overthinking, respondent V48 for example asks them to simply watch, listen and try to repeat, whereas, with children, he tries to stimulate self-awareness and self-evaluation:

> "Sometimes older people have more difficulties in reenacting the examples and in accepting concrete tips. Questioning or analyzing aspects of the violin playing too deeply sometimes stands in the way of acquiring new skills. They talk more about the difficulties they are having than children; they sometimes more easily 'take the plunge' without worrying too much about how or what (or why!). To adults I often say: don't think too much, just watch, listen and try. Children I often ask the question: what should you do, or what have you just done?" (V48)

However, sometimes, adult novices might be reluctant to accept teaching methods based on modeling and imitation:

> "Adults [. . .] are not open to the above-described exercises, simply because they think they can reason. Making adults feel something physical is often difficult, so you have to verbally explain it, which in turn becomes very complicated because you have to think about a lot at the same time" (V50)

And as a consequence, teachers might refrain from using these techniques:

> "Children: demonstrate the movements enlarged. Also: 'this is how it should not be done'. You don't do this so easily with adults because you do not want to offend them." (D19)

The majority of violin teachers (78.1%, *n* = 32) agreed that physical interaction is key since it is required in all aspects of violin playing, i.e., for general posture, instrument and bow positioning, bow movement and trajectory guidance, bow and neck finger positioning, finger and hand placement, tension relaxation/optimization, elbow movement indication in string crossing, stage fright suppression, sound quality optimization, artistic expression facilitation and collective performance. 53.1% (*n* = 17) of drum kit teachers regarded physical guidance as pivotal, acknowledging its value to correct posture, showing a student how to hold and control a drumstick, guiding arm movement, and transmitting emotional and expressive content. Additionally, 56.3% (*n* = 18) of drum kit teachers acknowledged the importance of movement demonstration and imitation, and the relevance of playing along with students (e.g., to help them to maintain a steady tempo).

Attitudes toward wearable devices and virtual reality use

Wearable devices

According to 28.1% (*n* = 9) of drum kit teachers and 12.2% (*n* = 5) of violin teachers, a postural support device could help to reduce excessive fatigue and discomfort of novices after a class or training; 18.8% (*n* = 6) of the drum kit teachers and 39% (*n* = 16) of the violin teachers disagreed; respectively 21.9% (*n* = 7) and 17.1% (*n* = 7) of the drum kit and violin teachers were undecided; while 31.3% (*n* = 10*)* of the drum kit and 31.7% (*n* = 13) of the violin teachers did not have an opinion (see **Figure 1**). Generally, violin and drum kit teachers would rather recommend doing sports or specific exercises to increase muscle strength and prevent injury. They were mainly concerned that the use of such devices could have undesired effects:

> "I do not know whether, with the help of such a device, the proper posture reflexes would be developed and whether such a device would not stiffen the entire body and posture of the player, as the point is to seek natural freedom." (V37)

Moreover, they believed that wearable devices could be used for other purposes than mitigating fatigue and discomfort. According to drum kit teachers, ideally, wearable devices would correct posture, enhance drumstick grip and movement, provide feedback and facilitate mirroring of the observed movements (see **Table 3**). For violin teachers, optimally, wearable devices would stabilize overall posture, relax shoulders and other joints, keep the left wrist in the correct position and prevent the fingers of the left hand from being clenched. Design ideas included equipment for straight bowing and a restrictive device inhibiting all other movement except for that of the elbow and forearm. **Table 3** further outlines these recommendations.

One of the main concerns regarding wearable device use is that it might impair certain aspects of the learning process. Some brought up device dependency as a potential risk, with students trusting in the efficacy of the device rather than employing their own cognitive and motor capabilities. As a consequence, if the device would be removed, bad habits might return.

> "With aids, it is often the case that if you stop using them, you start making the same postural mistakes again." (V62)

Virtual reality

Most respondents (79.5%, *n* = 58) were inexperienced with VR. When asked whether, in their opinion, the use of VR could facilitate musical skill development, 19.2% (*n* = 14) of the teachers responded positively, 27.4% (*n* = 20) were somewhat hesitant, 23.3% (*n* = 17) were not in favor of employing VR, while 30.1% (*n* = 22) had no opinion (see **Figure 1**).

Teachers who recognized or were undecided about the potential of VR believed it could be especially useful for distance learning, posture correction and overall motivation. Furthermore, they presumed that VR use could facilitate motor skill development, but largely discredited its potential to improve other musical skills or sound quality:

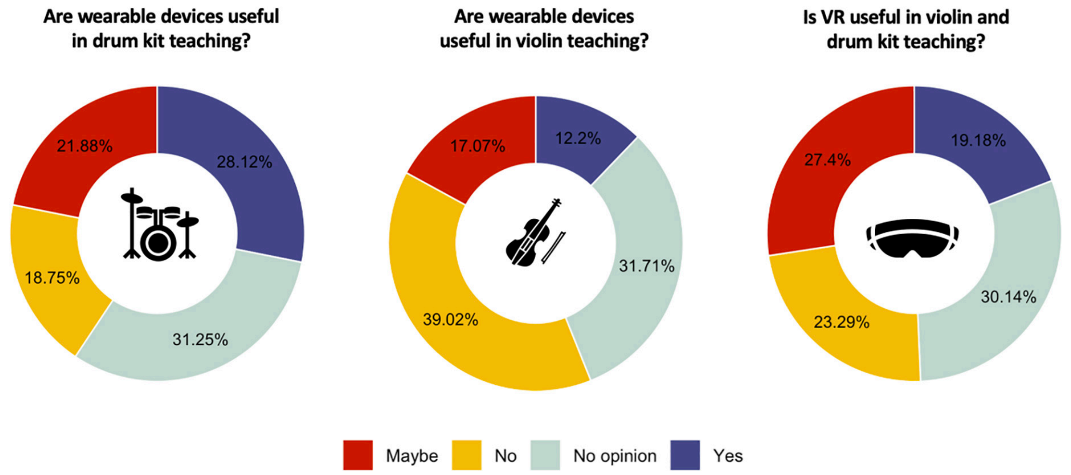

FIGURE 1
Teachers' opinions about usefulness of wearable devices and VR applications in violin and drum kit training.

> "Musicality seems difficult to practice given the virtual situation. However, coordination/motor skills seem to be fine to practice. VR can be useful for teaching new movement combinations." (D15)

> "Yes, if the virtual world responds to errors such as in a computer game, e.g., the student 'drowns' (the environment becomes water) if his arms drop too much. Real muscle training. For the rest, I don't think VR can be used." (V61)

> "Probably for developing motor skills, it could provide good results. However, musical skill development requires lively contact with people, communing with beauty and music, and an attempt to simplify this path will not have a positive impact on shaping the sensitivity and musical individuality of a young art adept [. . .]." (V43)

At the same time, respondents were afraid that VR tools might fail to provide correct feedback since teachers commonly adopt tailored communication strategies when dealing with students. Additionally, they were concerned about the lack of physical interaction in the VR environment, as *"touch seems to be an integral part of motor memory and, at the moment, I have no idea how to bypass/replace it."* (V36). Furthermore, their answers also touched upon the practicality as well as the technicality of VR:

> "If it can be integrated playfully and does not take too much time [to set it up], this can certainly be an asset. Especially if they can also use it at home." (D24)

> "It could of course help, but I think it would be quite laborious in terms of setup and technical requirements." (D13)

More hesitant respondents also stressed the need for optimal technical rendering:

> "Virtual reality has nothing to do with playing music. [. . .] The only way it could help would be when technology evolves to the point of holographic technology, and real-time recording and teaching. Let's wait for that." (D30)

Furthermore, they were also concerned that "*the subtle nuances in playing an instrument would be lost*" (D22) and that "*there is way too much technology in the life of students already*" (D10). For a more elaborate description, see Table 4.

Discussion

This paper investigated learning profiles of novice students and teachers' opinions on the potential supportive role of new technologies in music education. As an increased understanding of the needs and challenges encountered while teaching could improve the design of technological tools facilitating skill acquisition and technology adoption in the studio, we examined distinctions between adult and child novices, explored teachers' attitudes toward postural support devices and VR applications in instrumental music training and considered suggestions regarding device design.

TABLE 3 Teachers' design ideas for wearable devices.

Objective of wearable devices	Illustrative quotes of design ideas
To correct and stabilize overall posture	"I think most students should especially pay attention to their back [posture/position]; so, a kind of little harness to avoid sagging on the drum seat?" (D31)
	"Something to keep the chest open and the chin tucked back for a normal good posture." (V46)
	"A center of gravity scanner with an audible signal for excessive deflection would probably make the most sense. Most posture problems begin with bad daily habits. Posture problems only further emphasize the existing flaws." (V36)
To give real-time feedback and indicate errors	"A device that registers how the student plays and immediately indicates what is wrong, a camera that indicates which zones must be adjusted + checks tone formation (correct playing field, full stroke,.). And if a program can be connected there where you can set methods, then that would be handy. Less dragging around with books! + ability to download and play music." (D24)
	"Quite simple: a robot that is mirroring your movements in exactly the same way." (D12)
To relax shoulders and other joints	"No idea what it should look like. The device should facilitate a relaxed posture. This means that when the drummer sits down on his drum seat, all drums/cymbals/feet should be positioned so that they can be reached with a minimum of physical effort. Upper arms should fall next to the body, completely relaxed." (D15)
	"To develop and relax wrist muscle." (D25)
	"[. . .] muscular tension tracking devices." (D07)
	"Device to relax shoulders while playing. Most students have too much tension in fingers –> elbow –> shoulder." (D49)
To stimulate correct upper limb movement and hand grip	"Perhaps a controlled harness that can make the student feel the required movement and experience the synchronization between hands and feet." (D28)
	"A device that shows the stick bouncing on the skin (trampoline principle), and we use the 'force' of the skin to make the stick bounce back." (D19)
	"It would be some sort of separator for the first and second fingers in the left hand. It would prevent the fingers of the left hand from being clenched. Also, something that would reduce the clenching of the thumb on the left hand would be helpful." (V33)
	"Device 'blocking' the right elbow from rolling backward." (V40)
	"A stand to put the right elbow in, which can be adjusted according to the string on which one strikes. Pole with holder. Serves to bow straight from center to tip." (V51)
	"Something to clamp on the left shoulder over which you can slide a stick (guided) in a similar way as when you bow on the violin." (V63)
To support students' practice at home	"A device could be a small robot that takes over the movement we did in class and then does the exact same guidance during practice at home. But this would presumably require extensive means to provide this for every novice student." (D32)
	"Something that also gives the student all the necessary information regarding the exercises to be performed at home and provides the necessary feedback in case of mistakes (also in posture)." (D22)
Other	"Automatic lights on the sticks or drum set that blink in the same rhythmical pattern. This give the student a sense of playing a computer game." (D06) "Foldable electronic drum kit." (D13)

TABLE 4 Teachers' design ideas for VR applications.

Objective of VR application	Illustrative quotes of design ideas
To demonstrate movement	"When the student can better detect whether he bows straight, it might be easier to correct it." (V53)
	"If they get more and better visual feedback about their movements as a result, it can certainly help. Now it is difficult to see all movements (such as straight bowing); even in a mirror, this is not evident." (V70)
	"A hologram of someone playing with a perfect technique; speeding up, slowing down, zooming in and out on every aspect of gameplay. Such virtual models are used in sports, for example for professional swimmers." (V48)
To correct posture	"This may help to demonstrate the correct posture and amplitude of body movement, in respect to their body size ratio." (D06)
To indicate errors	"Holding the stick and seeing different angles, developing coordination." (D09)
To work on stage experience	"Jamming with other musicians like guitarists or pianists. This may help them to experience how to combine their simple drum patterns with other musical input. To increase their aural skills in ensemble/band playing." (D06)

Age appropriateness

Our results suggest that the learning profiles of novice violin and drum kit students are of similar nature and follow general developmental stages. We observed clear differences depending on the age of the students (i.e., young vs. adult novices), but less relating to the musical instrument (i.e., violin vs. drum kit). Hallam et al. (2018) investigated the differences between instrument groups with regard to motivation and practice. On the one hand, they found differences in the amount of time spent practicing in relation to instrument groups, with string and guitar players practicing the most and singers the least. On the other hand, the amount of practice as well as most of the other items that differed significantly were mediated by age or differed only in relation to students' age. Age-related differences can be related to Piaget's Four Stages of Cognitive Development (i.e., the *sensorimotor stage, preoperational stage, concrete operational stage and formal operational stage*), describing how our cognitive processes change as we grow (McLeod, 2010). They are also in accordance with the account of Goodway et al. (2019) regarding motor skill development, which discusses gradual changes between eye and limb coordination, reaction times and muscle development in relation to age. Children who start to learn to play violin or drum kit are most commonly between 7 and 11 years old and are usually at the *concrete operational stage*. This stage is characterized by the development of organized and rational thinking that can only be applied to previously encountered physical objects (Goodway et al., 2019). More abstract cognitive abilities and self-consciousness emerge by the end of this stage. In contrast, adult novices are commonly at the *formal operational stage* and are able to imagine the outcome of particular actions and use abstract reasoning (McLeod, 2010; Goodway et al., 2019). Hence, they can more clearly foresee the benefits of regular practice and usefulness of particular exercises for specific musical skill development. Furthermore, children initiating the *concrete operational stage* (6–7 years old) tend to have more difficulties with eye-hand and eye-foot coordination (Goodway et al., 2019). However, when children are given the opportunity to practice and experiment with their coordination, the integration process of perceptual and motor abilities occurs more rapidly and limb coordination is usually well established by the end of this developmental stage (11 years old) (Goodway et al., 2019). In contrast, adults undergo structural changes in joint and muscle tissue, which lead to a gradual decline in joint flexibility and detrimental motor performance causing a reduced capacity for adaptive change in the motor output (Abernethy et al., 2018). Hence, these developmental stages can indeed help to explain why, at the start of the learning process, children are inclined to progress more slowly, yet tend to outperform adults after some time and practice. However, even though cognitive processes and motor skill development are already well described in music pedagogy and psychology, developers rarely use this wealth of knowledge when designing technological tools (Revelle, 2013).

This study demonstrates that, for violin as well as drum kit teachers, tailored, age-appropriate instructions and communication strategies are essential in order to tackle the wide range of challenges encountered when dealing with novice students. However, in music education, technologies are often applied and designed for specific instruments (Grindlay, 2008; Löchtefeld et al., 2011). Arguably, an instrument-specific design is more straightforwardly related to technological aspects (e.g., correct rendition of specific movement trajectories, device placement avoiding movement obstruction, etc.) than to pedagogical and developmental aspects. This technology-driven design has been criticized in the literature as it often neglects the opinion of the end user and numerous variables inherent in the learning process (e.g., Revelle, 2013; Malinverni et al., 2016). Our findings suggest that physical, cognitive, social and emotional developments of specific age groups should be taken into account during the design process. In doing so, when being used by novice students, wearable devices and VR applications could more adequately support and facilitate postural development and enhance optimal movement trajectory execution.

Practice at home, playfulness and social interaction

According to the participants in our study, engagement in practice at home is a key challenge for adult and child novices. Teachers propose to seek collaboration with parents as a potential solution to keep young novices motivated to practice at home. This is in line with studies on motivation and dropout prevention in music education, which highlight the relevance of interpersonal dynamics between the teacher, caregivers and child in order to develop a long-term commitment to engage with music (Davidson et al., 1996; Zdzinski, 2021). A study by Costa-Giomi et al. (2005) showed that, when compared to novices who persevered with piano lessons, novice pianists who dropped out had looked for more (yet received less) approval from the teacher at an early training stage. As another possible solution to keep children engaged with practice, teachers propose using positive reinforcement (e.g., stickers and class concerts). Contrastingly to children, in order to motivate adults to regularly practice at home, teachers in our study suggested to create work plans and select varied, musically engaging exercises.

Given the above-described results, ideally, assisting technologies should integrate playful activities and enable social interaction for young as well as adult novices. The introduction of gamification elements into teaching/learning strategies (i.e., earning virtual goods such as badges or points, leveling up), for instance, was shown to improve educational outcomes, motivation and engagement with the learning material during botanical classes (Su and Cheng, 2015) and second language English courses for primary school students (Sandberg et al., 2011). Such an approach enables learners to carry out tasks in a relatively relaxed and pleasant environment, where effort, rather than mastery, is rewarded (Ofosu-Ampong, 2020). Moreover, it might help to reframe failure as an essential part of the learning process (Su and Cheng, 2015). Also in the musical domain, *"the playful experience of working with music technology, together with the rewarding sounds that can be produced by it, provide strong motivators for young children to experiment and develop their musical ideas"* (Rowe et al., 2017; reported in Liu-Rosenbaum and Creech, 2021, p. 436). Notably, studies exploring the potential of the MIROR-Impro system (a program that enables interactive improvised musical dialogs with a computer) suggest that experiences with music technology are particularly rewarding for children when they are shared with their peers or teachers (Wallerstedt and Lagerlöf, 2011; Lagerlöf et al., 2013). Also, research focusing on adult engagement with music suggests that, rather than skill acquisition, this group especially values a strong focus on social interaction and musical enjoyment (Roulston et al., 2015; Zhukov, 2021).

Tailored learning and communication

The results of our study indicate that teachers differentiate their communication strategies according to the students' age. With adults, verbal instruction prevails. On the one hand, teaching strategies correspond to the finding of Howard et al. (2007) that adults might benefit greatly from clearer verbal instructions, which are especially sensitive to teaching style idiosyncrasies. Teachers in our study reported on their use of specialist terminology, such as muscle and joint names, and describe movement sequences in detail. On the other hand, by directing (too much) attention toward the student's body movements, teachers might end up obstructing elements of the movement execution. This phenomenon is referred to as "paralysis by analysis" (Ehrlenspiel, 2001) and describes how too much focus on the properties of the execution can eventually inhibit the intended action (Allingham and Wöllner, 2021). Allingham et al. (2021) emphasized that redirection of attentional focus (only through verbal instruction) can significantly improve learning outcomes in violin playing. Somatic attention focus that directs awareness toward tactile feedback (e.g., to the resistance of the violin bow against the strings) significantly improved performance on spectral centroid, bow contact point consistency, shoulder muscle activity and novices' violin sway in comparison with redirection of the focus to sound (external focus) or arm movement (internal focus). At the same time, several teachers acknowledged the difficulty to transfer knowledge to adult novices through modeling, since they do not always feel comfortable with this way of communicating.

Considering these findings, it is worthwhile to reflect on the goals of music educational technologies. As they are often driven by the desire to reduce the ambiguity that may characterize student-teacher interaction through verbal feedback and modeling (Howard et al., 2007; Grindlay, 2008; Blanco et al., 2021), such technologies display detailed information on one's performance [e.g., bowing movement, posture; see for example Amir (Ng and Nesi, 2008), MusicJacket (van der Linden et al., 2010) and TELMI (Blanco et al., 2021)] and as such may support the internal attention focus. A suggestion would be to use technology that challenges and expands the skill acquisition process, i.e., for adult novices it might be redirected to visual, auditory and physical channels, and (somatic) external focus instructions, while for children it might be directed toward exercises that increase self-awareness. An example of a tool that aims to enhance the skill acquisition process is the Music Paint Machine, a system that allows a musician to draft a digital painting while playing a traditional music instrument and manipulating properties of the music (e.g., pitch, amplitude) as well as body movements (e.g., twisting the upper body and moving the feet) (Nijs and Leman, 2014). This interactive music system does not aim to monitor errors, instead, it supports instrumental music instruction by inviting students to explore and experiment with the music, the instrument, the body and the visual representation of movement and sound (Nijs and Leman, 2014). Additionally, it augments the dynamics of the master-apprentice model by promoting sensations of autonomy and agency.

Visibility

Overall, our respondents did not seem to be inclined to equip their students with wearable devices or VR applications in daily practice. This might relate to the fact that teachers were relatively inexperienced with these kinds of technologies and might lack the capability to judge their usefulness or to envision potential applications for their teaching routine. Also, teachers who expressed more straightforward positive or negative opinions regarding the application of such tools were mostly concerned with technical rendering and usage complexity. These findings confirm the relationship between technology acceptance, perceived usefulness and willingness to apply the tool (Teo, 2009; Teo and Bahçekapili, 2012).

Given our respondents' overall unfamiliarity with technologies such as VR and wearables and their hesitance to use them, it would be fitting to increase the visibility of these technologies by involving teachers from the initial stages of technological development (Bobbe et al., 2021) or through more ecological study design (van der Linden et al., 2011). Researchers acknowledge three main points that need to be considered when creating an effective learning device, i.e., matching the device to the experience of the user, considering the task level and scrutinizing how to involve the teachers in training (van der Linden et al., 2011). Yet, in practice, these principles are hardly fulfilled as the end users are generally involved when the product design is already finalized (van der Linden et al., 2011; Bobbe et al., 2021). The aforementioned

TPACK framework and SAMR model might help to facilitate communication and mutual understanding between educators and developers regarding technology integration in music education contexts (Bauer, 2014; Mroziak and Bowman, 2016). These frameworks might actively engage teachers to reflect on all the encountered learning tasks and challenges while teaching with or without technology. At the same time, SAMR and TPACK might help developers to determine the complexity of technology design and its integration in specific contexts (Hilton, 2016).

Cooperative and collaborative teaching styles

In our study, teachers' design ideas for wearable devices predominantly addressed sensorimotor skill monitoring, including feedback regarding overall posture and control of limb movement. Also, VR applications were expected to provide students with postural feedback, movement demonstration and general error indication. The focus on movement and posture monitoring (instrumental gestures) might be explained by the prevailing educational approach in instrumental music education, namely the master-apprentice approach (Bowman, 2002; Lehmann et al., 2007; Schiavio et al., 2020). This approach may provoke an instrumentalist's conception of the musical instrument as well as the body (see also: van der Schyff, 2015a,b), in which both are considered as mere tools serving the technically perfect reproduction of the written music. In such an approach, the monitoring of movements and postures is at the core of the instruction. At the same time, our findings suggest that teachers would be rather reluctant to use monitoring technologies as they worry that the learner might start to rely more on the device, rather than trusting in his/her own mental and motor processes, to correct mistakes. Therefore, new interactive technologies such as wearable devices and VR applications could go beyond merely monitoring performance and reinforcing a teacher-centered master-apprentice approach. Instead, they could contribute to the development of students' self-efficacy and stimulate educators to engage with cooperative and collaborative learning/teaching styles (Welch et al., 2005; Collens and Creech, 2013; Gaunt et al., 2021). These technologies could provide new insights into music education and help to support transformational models of music learning, promoting long-term engagement in music study (Varvarigou and Creech, 2021).

Limitations

Some limitations of this study need to be acknowledged. In this study, we did not inquire about *subjective educational theories* (Kelchtermans, 2009) nor conducted field studies on respondents' teaching methods in practice. *The subjective educational theory* is an important component of the teachers' personal interpretative framework, which is developed throughout their career and might substantially impact their perception of the usefulness and potential of technological support for instrumental music education (Kelchtermans, 2009; Bauer, 2014). Furthermore, we mainly focused on sensorimotor skill development, hence, teachers could be biased toward formulating their answers from this perspective. In future research, aspects of expressivity and other musical skills could be investigated in greater detail. Forthcoming work could also employ a wider range of technologies and adopt a longitudinal research design. Ideally, it should also involve students, since they are also foreseen end users; their ideas and feedback would for instance be useful to consider when developing esthetical properties of such applications (Bobbe et al., 2021). Future work might also focus on the evaluation of specific scenarios of technological device and application use. Moreover, it could more strongly target the teacher-student relationship, as well as music educators' overall motivations and approaches.

Conclusion

In conclusion, by overcoming some of the limitations of more traditional strategies, wearable devices and VR applications might have the potential to enhance overall music training quality by addressing physical, cognitive, social and emotional developments of specific age groups, expanding the student's skill acquisition process through a multimodal design as well as enhancing social aspects of music learning/playing. This study identified several important factors of the technology design process that would benefit from user involvement in all stages of technology development and could improve student-centered training design, enhance motivation, boost the overall learning process and promote healthy and positive lifelong engagement with music.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors upon request, without undue reservation.

Ethics statement

This study involving human participants was reviewed and approved by the Ethics Commission Faculty of Arts and Philosophy, Ghent University. The participants provided their written informed consent to participate in this study.

Author contributions

AM and AC participated in the design of the study and carried out the thematic analysis. AM carried out the study, processed the data, and performed descriptive analysis. AM, LN, and EV carried out manuscript preparation. AM, LN, EV, and ML read and approved the final manuscript. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2022.1027042/full#supplementary-material

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