Internet of Musical Things for Children

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***Abstract*—One of the musical activities that can be positively impacted by the Internet of Musical Things (IoMusT) is music education. However, although the IoMusT's properties hold a promising potential to enrich music learning processes, the extent to which early childhood music educators and scholars have embraced this emerging type of technology and explored their potential is still very limited. To bridge this gap, we first survey the relevant literature at the confluence of the Internet of Things, music technology, and education. Then, we propose a pedagogical framework to support designing IoMusT applications for early childhood music education. The framework is based on five dimensions: embodied sense-making, non-linearity, participatory sense-making, privacy and security, as well as accessibility and inclusiveness. Furthermore, we corroborate the framework with a set of pedagogical scenarios showing its usage. Our study aims to foster interdisciplinary research at the confluence of pedagogy and music technology in an application domain, that of early childhood music education, hitherto unexplored.**

***Index Terms*—IoMusT, IoMusT, Early Childhood Music Education, Embodied Music Pedagogy, Embodied Sense-Making, Non-linear Pedagogy, Participatory Sense-Making**

I. Introduction

Expressing oneself musically is a basic and innate human ability. For example, newborns already exhibit sensitivity to music [1] [2], and the mother-infant interaction displays tonal synchrony based on harmonic and pentatonic series [3]. However, according to Gordon [4], people are born with different degrees of musical aptitude, i.e., the potential or capacity for musical achievement. Although this potential is innate, the child's environment and early musical experiences determine the degree to which this potential is actualized. Up until the age of nine, music aptitude is believed to be dynamic and fluctuating according to environmental influences [4]. Early exposure to music and music instruction can play an important role in actualizing a child's musical potential. Therefore, it is crucial to provide children, from early childhood (0-8 years) on, with enriching experiences that allow them to develop their natural musical and expressive abilities and realize their potential for music. It is important to note that the realisation of such potential is not a prerequisite to enjoying a musical experience. Such enjoyment rather stems from, for example, a balance between the child's skills and the challenge posed by the musical experience [5].

One way of enriching children's early childhood musical experiences involves using technology. Young [6] distinguishes between everyday digital music experiences and integrating new technologies to enhance practice. Concerning the latter, the author further distinguishes between technologies dedicated to music educational practices and ubiquitous and hand-held technologies such as tablets. Young [7] (p. 695) also asserts that "digital technology, where available to children, is changing the nature of music and musical practices, particularly in family homes", and demonstrates that technologies at home have broadened the way in which children engage with music.

In recent years, technologies, such as digital musical instruments for children, musical toys, mobile apps, digital games, or play maths have been designed, developed and found their way into children's home environment. However, according to de Vries [8], early childhood music teachers do not adopt in the classroom the types of technology that children interact with in their home environment. Yet, using such music technologies could have several benefits for early childhood music education (ECME). For example, they can provide an alternative to traditional musical instruments that are most often not adapted to the physical abilities of young children and, as such, offer opportunities to nevertheless engage in music making [9]. In addition, technology may support extending conventional classroom practices and introducing novel pedagogical approaches [10]. Research also shows that technology integration in early childhood education (including ECME) promotes, for example, multimodal learning [11], student engagement and motivation [12].

Despite these benefits, technology adoption in the early childhood classroom is still scarce [8] (see also [13] [14]. Moreover, Ling et al. [15] (p. 6334) also argue that there is still a great necessity to investigate the use of new technologies in early childhood education "in order to recognize and utilize the benefits and to minimize the potential risks".

In this paper, we aim to contribute to the advancement of the educational use of technology in early childhood, both to enrich musical experiences at home and in early childhood education. We focus on a specific type of technology, namely the Internet of Musical Things (IoMusT), which refers to the extension of the Internet of Things (IoT) paradigm to the musical domain. More specifically, the IoMusT relates to "the ensemble of interfaces, protocols, and representations of music-related information that enable services and applications serving a musical purpose based on interactions between humans and Musical Things or between Musical Things themselves, in physical and/or digital realms. Music-related information refers to data sensed and processed by a Musical Thing, and/or exchanged with a human or with another Musical Thing". A Musical Thing is defined as "a computing device capable of sensing, acquiring, processing, or actuating, and exchanging data serving a musical purpose" [16].

Although IoMusT's properties hold a promising potential to enrich music learning processes, the extent to which early childhood music educators and scholars have embraced this novel type of technology and explored their potential is still very limited. For example, in their systematic review, Kassab et al. [17] show that only a few studies on the educational use of IoT address primary education (11% of the studies) and early childhood education (3% of the studies). Yet, according to Lechelt et al. [13], education needs to converge with recent technological developments and provide learners with hands-on experience with IoT, of which IoMusT is a subdomain. The slow adoption of Io(Mus)T in education might be explained by a lack of knowledge, intention, and understanding in creating a learning environment that incorporates the use of Io(Mus)T technologies for teaching and learning, as well as the instructional designs that use such technologies [18]. Arguably, this lack concerns teachers' "TPACK", i.e., teachers' ability to effectively integrate technology into their teaching practices and enhance student learning outcomes [19]. In addition, the difficult adoption can be related to teachers' technology acceptance, in particular the perceived ease of use and the perceived usefulness [20]. In our view, the perceived *pedagogical usefulness*, i.e., whether a technology can be used in a pedagogically sound and meaningful way, is a key factor in determining its acceptance and adoption.

Therefore, to advance this exciting and promising domain, we believe it is important to establish a pedagogical framework that may support the design of IoMusT applications and their implementation in early childhood music education, and as such contribute to the perceived pedagogical usefulness of Io(Mus)T. Currently, such a framework is lacking. In this contribution, we propose a series of pedagogical principles that may constitute a design and implementation framework for IoMusT applications for young children. In addition we propose some scenarios for the design and implementation of IoMusT for children, which illustrate our vision.

Notably, the present study falls in the remits of the "Internet of Musical Things and People" paradigm recently proposed in [21]. Indeed, the proposed vision considers not only children's values, needs, behaviors and diversity, but also their mutual entanglement with networked musical devices, services and environments.

The remainder of this article is organized as follows: Section II introduces some core aspects of ECME. Section III provides an overview of IoMusT in ECME. Section IV proposes a framework for an IoMusT targeting children. Section V illustrates our vision of an IoMusT ready for children through a set of pedagogical scenarios. Finally, Section VI provides concluding remarks.

II. Music in Early Childhood

To fully grasp the potential benefits of IoMusT in early childhood, it is important to consider some of the fundamentals of music learning in the early years.

First, music learning in the early years is *multimodal*. Children engage with all their senses and experience music through their sensorimotor, affective, and cognitive resources [22] [23] [24]. Accordingly, musical interaction is not a mere auditory experience but addresses the whole body. Precisely the bodily experience of music opens the door to the interplay of the senses, invoking the richness and meaningfulness of an empowering musical experience. As such, music learning is also *embodied* [25]. In addition to considering multimodal involvement with music as addressing all senses, it is important to note that, as Arnott and Yelland [26] argue, technologies can be regarded as a new modality in their own right. As such, integrating technologies into early childhood music learning, such as the IoMusT-based ones, can broaden the multimodal nature of music learning.

Second, music learning in the early years requires a *child-centered* approach. According to Niland [27] (p.19), this involves acknowledging the voice of the children, integrating "what children care about, what they already know, and what they would like to know" when deciding as a teacher on, for example, content, materials, and activities. As such, children are allowed to make choices, adapt, and extend the learning content.

Third, music learning in the early years is often about *participation and collaboration*. Through diverse musical activities, such as singing with an adult, inventing music together, or dancing, young children discover new ways to interact with others in and through music and learn about music in implicit, reactive, and deliberate ways [28]. In this context, the IoMusT can play a relevant role as it is committed to connecting musical stakeholders and to enabling new kinds of musical interactions among them.

Fourth, music learning in the early years is *active*. It involves the process of developing a sensitivity to sound by active participation in music activities, during which children gradually gain an understanding of elements in the music, such as melody and rhythm, and establish a meaningful connection with music [29]. Young children often discover music through playful and explorative activities, such as spontaneous singing, sound exploration, and dance [27].

III. IoT and Musical Things in Early Childhood

Given the above-described learning characteristics in the early years, the potential of IoMusT to promote a rich musical learning environment becomes clear. Within the scenario of enhanced music learning, Musical Things (i.e., computing devices capable of sensing, acquiring, processing, or actuating, and exchanging data serving a musical purpose [30]) such as *smart musical instruments* or *music haptic wearables* may support multimodal and embodied, participatory and collaborative, play-based and exploratory, and child-centred activities by introducing novel forms of interactions or by digitally augmenting existing activities.

In this section, we give an overview of existing work. Given the scarce number of studies in the domain of IoMusT, we start with the use of IoT in early childhood. Next, we focus on musical things, focusing mainly on early childhood music education.

A. IoT for children

According to Ling et al. [15], "IoT devices could provide the young children with opportunities to connect digital and physical worlds for their playful explorations, help them to build their knowledge base, arouse their interest and enthusiasm, and encourage them to be autonomous learners".

In the context of early childhood, an interesting subcategory of IoT are the IoToys. They differ from Smart Toys in that they are connected to online/digital platforms through Wi-Fi or Bluetooth. According to Ihamäki and Heljakka [31], they have three general properties. They are:

- Pervasive: allowing to follow children through everyday activities;
- Social: involving social aspects and multiplayer participation;
- Connected: connecting and communicating with other toys and services through a network.

IoToys are often equipped with sensors, allowing them to detect and capture different types of information, such as audio and video, as well as physiological and location records. Due to their connectivity, such information can be collected and stored (often through connection with a cloud server) for further use, such as exchanges through smartphone applications. An important aspect is that IoToys can be "smart" or "intelligent". That is, by embedding computers and running machine learning methods, the gathered data can be processed (e.g., pattern detection) to make decisions and, as such, offer personalized interactive and engaging experiences, whether focusing on entertainment or learning. For example, when interacting with a robot IoToy, if the child seems bored with a certain game, the robot can suggest a new activity that the child may enjoy more based on past preferences. If the child is frustrated, the robot can adjust its tone and responses to be more encouraging.

Accordingly, compared to traditional toys, IoToys introduce augmented responsiveness and interactivity. Moreover, they can become "teachable machines" [32] or tutees [33]. Consequently, as intelligent and teachable machines, IoToys may facilitate reciprocal tutoring.

While these aspects provide various benefits, caution is needed regarding the datafication of children's interaction with toys [34]. Indeed, the fact that IoTys can track and communicate personal, environmental, and behavioral data raises privacy and security concerns, as they can potentially be shared with third parties and used in unethical ways. IoToys often connect to cloud servers, which can be vulnerable to cyber attacks, putting user credentials, child identities, and personal information at risk. Consequently, IoToys such as "My Friend Cayla" or "Cloudpets" have been withdrawn from the market (see also [35]).

While designed as toys, IoToys can also be considered playful or tangible user interfaces, presenting a playful appearance that invites physical interaction [36]. Considering the connectedness and sensor integration, Mascheroni and Holloway [34] conceive IoToys as media. They can interact with users, collect data, and provide personalized experiences, resembling the functions of traditional media.

The review study by Ling et al. [15] indicated that IoT devices are used at home in unstructured play activities while at school in more structured play-based learning activities. Many young children use a repertoire of IoToys at home. Examples are little robots (e.g., Dash & Dot [37]), dolls (e.g., Hello Barbie [38]), blocks and modular toys (e.g., MakerWear [39]), and toy-gadgets such as watches [40]. However, the use of IoToys in educational settings is still limited or none [41]. In addition, the suitability of IoToys for early childhood education has not been systematically researched [31]. Yet, according to Ihamäki and Heljakka [31], it is necessary to acknowledge their potential to create opportunities for knowledge building and skills acquisition in the early years.

Ihamäki and Heljakka [42] conducted a 6-month longitudinal study with preschool children, investigating toy-based learning and the forms of play they may prompt. To do so, children were provided with the IoToys Wonder Workshop's Dash and Fisher-Price's Smart Toy Bear. Interestingly, the authors start from a categorization of different forms of play (see Table I), showing how different IoToys can promote different forms of play.

In a different vein, Miglino et al. [43] used Block Magic, a smart environment for children and teachers that enables children to engage in conventional play using familiar didactic materials, specifically the classic Logic Blocks, while also including a computer and specialised software to enhance the level of participation.

B. Musical Things for children

In 2018, Turchet et al. [16] proposed to extend the concept of IoT to the musical domain leading to the subfield of IoMusT. While the concept of IoMusT has only recently been introduced, some previously developed technologies align with the idea of using devices that "sense, acquire, process and exchange data serving a musical purpose", which is a central tenet of the musical things in the IoMusT vision [16].

One example concerns the musical toys developed at the at the Massachusetts Institute of Technology. Beatbug [44] is a handheld percussion instrument designed to promote collaboration. Up to eight Beatbugs can be connected to a computer, operating in 'snake' mode, i.e., starting with a short rhythm pattern that travels to another player who can manipulate the pattern to encourage interaction and communication between children. Several patterns can be combined [44] [45]. Musical Shapers are spherical musical instruments made of a soft squeezable material. By squeezing a Shaper with both hands,

TABLE I
DIFFERENT FORMS OF PLAY ACCORDING TO IHAMÄKI AND HELJAKKA [42]

Form of Play	Description
Exploratory	Learning about the properties and interactions of toys through physical skills and exploration of play options.
Constructive	Adding one's own voice to toys to make them more unique and making trails using programming or coding. Toys are used to make, recognize, and solve problems during this type of play.
Creative	Playing with toys in open-ended ways like care-taking (e.g., playing house) or coding (e.g., programming the toys to move) and using other materials like art supplies to encourage fluency, flexibility, originality, imagination, and new connections.
Pretend, fantasy and socio-dramatic	Role-playing, pretending with things, activities, and circumstances with toys in the imagined play frame to create an episode or event.
Physical locomotor	Various physical exercises for their personal fun and toy use. In this style of play, children learn motor skills and use toys in physical and social play.
Language	Spontaneous interactions with sounds (e.g., by recording one's own voice to toys), playing with rhythmic and repetitive elements of words (e.g., coding sounds for the toys and making the toys move with the sound). For older children, this might involve rhyme, word play and humour.

children can manipulate musical parameters such as contour, timbre, density, and structure [46].

The Musical Fireflies are palm sized digital musical instruments that introduce mathematical concepts in music such as beat, rhythm and polyrhythm without requiring users to have any prior knowledge of music theory or instruction. Through simple controllers, the Fireflies allow users to input rhythmic patterns, embellish them in real-time by adding rhythmic layers, synchronize patterns, and trade instrument sounds. Since interaction with other players increases the richness and complexity of the experience, the Musical Fireflies also motivate collaboration and social play.

Another example is Kibo, an interactive wooden instrument with a simplified tangible interface that embeds a MIDI-compatible controller to communicate with other MIDI devices (e.g., synthesizers and sequencers) and iPhone, iPad or a Mac (via an app) [47]. Interaction modes involve inserting and extracting tangibles from the base and pressing and releasing the tangibles.

While the above examples concern multidirectional communication between users within a local network, IoMusT adds interconnectivity through the internet and, thereby, the possibility to transform situated into remote interaction. In the domain of music education, the combination of remote learning and musical things is almost non-existent. One example is the SYNTH4KIDS, developed by Christou [48]. Synth4kids is a web-application designed for children from 5 to 8 years old, involving a monophonic synthesizer based on analog synthesis and focused on electronic sound production. The system can be connected to devices such as LeapMotion(TM) or tactile interfaces such as Makey Makey (TM).

IV. A DESIGN FRAMEWORK FOR IOMUST FOR CHILDREN

As the overview of applications in music education suggests (see Section III), their adoption in the music educational domain is still in its infancy. This offers the chance to lay out a framework for upcoming developments while promoting a technology-inspired but pedagogy-driven approach. The basis for this framework is Embodied Music Pedagogy, as proposed by Bremmer and Nijs [49] [50] to advance the domain of music education in line with the most recent findings in disciplines such as pedagogy, musicology, sport sciences, or psychology. Here, we focus on three core principles of this educational framework, namely embodied sense-making, non-linearity, and participatory sense-making. Taking into account the connectivity of IoMusT through the internet, another principle is added, namely privacy and security. Moreover, considering the tenets of Universal Design [51], the principle of accessibility and inclusiveness are included.

These five pillars of the framework are detailed hereinafter. A schematic representation of our framework is depicted in Fig. 1.

A. *Embodied Sense-Making (ESM)*

A core idea of Embodied Music Pedagogy is that music learning and teaching involves a dynamic interplay between teacher, learner, and learning content, whereby the body plays a fundamental role in the communication between learners(s) and teacher through/with/in sound. Communication in and through music implies the ability to make sense of the music. According to Leman [52], musical sense-making involves the transformation of a stream of sounds into a meaningful musical whole, based on the association of patterns in the sounds (e.g. chord sequence or melody) with movement patterns (e.g. shape, direction, energy) and thereby with the intentional states (e.g. an emotion) that underlie these patterns.

Leman [52] proposes three basic mechanisms that shape enactment:

- *Entrainment:* the process of being pulled towards synchronization with the music or with others;
- *Prediction:* the ability to sense what comes next in the music;
- *Alignment:* the ability to align one's movements to certain musical aspects.

As each of these mechanisms is rooted in bodily engagement based on body morphology, reflexes, and a learned movement repertoire, musical sense-making is profoundly embodied.

The IoMusT may provide ample opportunities to address these basic mechanisms and, as such, to contribute to the process of finding or creating meaning in the music and sharing that meaning. For example, Gali et al. [53], in an XR environment, used a handheld object to decrease the degree of

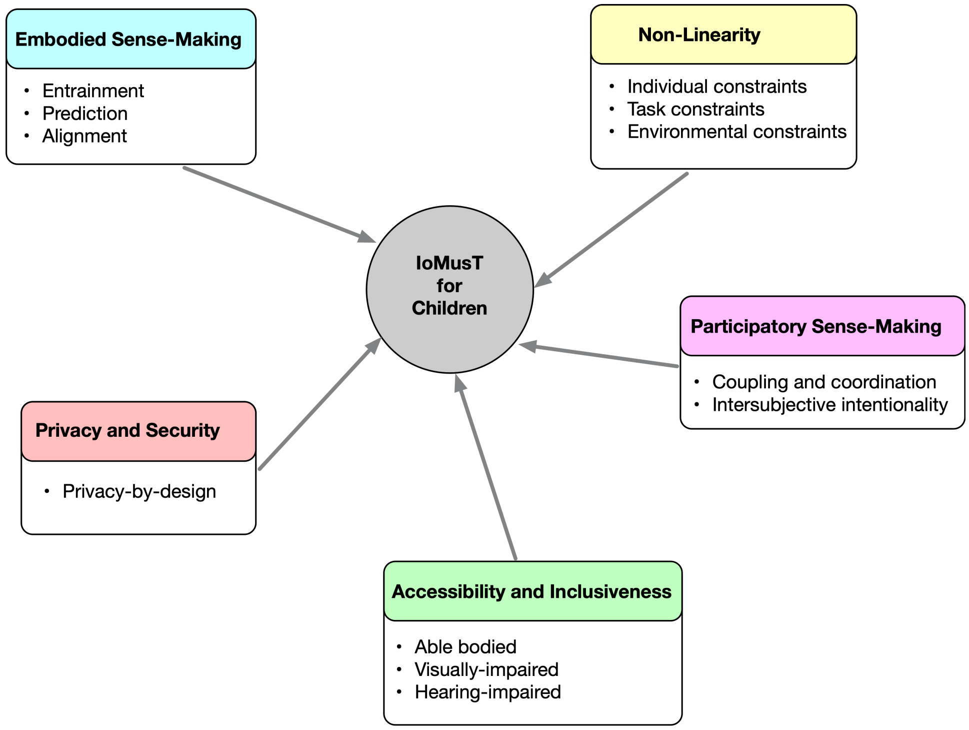

Fig. 1. A conceptual diagram of the interconnected components in our vision of the IoMusT ecosystem for children.

freedom of movement. The system was designed to improve young children's full-body Interpersonal Entrainment, and the object helped the system identifying every child by a distinct color.

B. Non-linearity (NL)

While music education is often structured in a linear way, guiding students systematically along a predetermined learning path, Embodied Music Pedagogy embraces non-linearity as an important aspect of music learning and teaching. Based on the idea that a music lesson is a dynamical system [50], learning emerges and self-organizes through the dynamic interaction between the learner, the teacher, and the learning content. The dynamics of a music lesson and the process of emergence and self-organization can be shaped through a set of constraints (see also: [54]). There are three types of constraints:

- *Individual constraints:* they refer to an individual's characteristics, such as perceptual, emotional, and cognitive functioning, or motor abilities [55]. Individual constraints can be *structural*, i.e., aspects of the individual's body structure (e.g., length of legs), or *functional*, i.e., body functions such as balance, coordination, agility, and cognitive functioning (e.g., motivation, attention).
- *Task constraints:* they refer to the goal of a specific task, to the feedback on the task, asking questions, or the materials used during a learning experience [56] [57].
- *Environmental constraints:* they refer to the physical factors surrounding learners, shaping or limiting their behavior [56].

Importantly, in this view, the teacher is not seen as a mere manipulator of constraints, but as part of the music lesson as dynamical system [58].

IoMusT applications may provide multiple opportunities to manipulate these constraints and thus shape emergent learning through the process of self-organization. For example, when integrating machine learning, IoMusT applications can learn about individual and group behavior during a learning activity. Consider joint walking to the music, while using an IoMusT application to make sounds together. By altering the tempo, structural individual constraints can be addressed, as the ability to synchronize in a certain tempo is related to, for example, age [59], and length of the legs [60]. In addition, functional individual constraints can be manipulated through differentiation, gradual increase of task difficulty and complexity, and task variability [61]. Also, the IoMusT can help manipulate task constraints by, for example, providing different types of feedback (e.g., visual, vibrotactile or auditory) or feedback on different music elements (e.g., level of synchronization between learners).

Finally, the IoMusT can help manipulate the environmental constraints. As smart devices Musical Things can, for example, respond to the users' actions in space (e.g., modify the sound output based on the proximity or movement of performers), augment the environment with auditory, visual, or even haptic cues that guide learning and creativity, help tailor the learning environment to suit better individual progress and challenges (e.g., altering background tracks, tempo, and harmony based on the learner's performance), or create a shared musical environment that transcends physical boundaries (e.g., connecting musicians from different locations) and as such allow musicians to experience and adapt to new acoustic environments and social interactions.

C. Participatory sense-making (PSM)

Participatory musical sense-making involves participating in each other's sense-making of music through a shared, active involvement in music (see [62], p. 31). It allows for the co-creation and joint understanding of music as it develops over time. To foster participatory sense-making, it is important to create a close coupling and coordination between individual learners and, as such, produce a shared context based on intersubjective intentionality, i.e., the collective experience of meanings [63] [64].

The IoMusT offers an excellent opportunity to create such a close coupling and coordination between individual learners. Indeed, an IoMusT infrastructure encompasses hardware and software (such as sensors, actuators, devices, networks, protocols, APIs, platforms, clouds, services) that enable the creation of an ecosystem of interoperable devices connecting learners and teacher with each other.

D. Privacy and security (P&S)

In order for the IoMusT to be ready for children it is paramount to address any potential risk for misuse of digital identities, and any sort of data ascribable to a child. Therefore, it is critical that privacy and security methods are considered since the early stages of design of Musical Things, IoMusT ecosystems, and applications. For this purpose, it is important that IoMusT manufacturers rely to privacy-by-design methods (see e.g., [65] [66]), especially to comply to the legislation on the matter [67].

E. Accessibility and inclusiveness (A & I)

The IoMusT can also be exploited in pedagogical situations that involve learners with, for example, visual or hearing impairments. This is possible thanks to the so-called musical haptic wearables [68]. These are wearable devices encompassing sensing, wireless communication, and haptic actuation (such as vibrotactile motors).

In the context of visual impairments, it is possible to use the sense of touch as a means of communication to provide musical information. For example, in [69] the authors developed a system enabling an ensemble of visually-impaired performers to exchange musical information related to tempo variations (e.g., accelerando, decelerando), tempo synchronization, or start/stop playing, and react to them. The same concept can be used during for educational purposes.

Regarding hearing-impaired users, including those with cochlear implants, the sense of touch can be leveraged to provide a real-time tactile representation of the music played or listened, thus providing a means for coping with the auditory deficit. An IoMusT system that can be adapted to such scenario is reported in [70].

These IoMusT systems have the potential of making music education not only more accessible, but also more inclusive. This is especially true in contexts of group lessons involving both able-bodied and sensory-impaired learners.

V. Educational Scenarios

In this section, we propose a series of educational scenarios that concretely illustrate the above-described framework. The first three scenarios concern classroom practices involving connectivity through a local network. The fourth scenario concerns connectivity through the internet.

For all scenarios, we devise a prototype Musical Thing that incorporates different inertial sensors, allowing to track for example quantity of motion, position in space. Furthermore, we envisage an interface that allows a teacher to activate certain presets (e.g., pertaining to a specific activity), to couple or decouple the different devices (e.g., group in pairs or per four, connect all, disconnect all), upload or choose backtracks from a library. The proposed scenarios can be implemented with current technologies.

A. Scenario 1: Sound Creation

Musical activities often involve predetermined sounds, based on the instruments or tools that are involved. These can be, for example, traditional instruments, Orff instruments, or Boomwhackers®. Alternatively, children could work with sounds they create for themselves, thereby promoting ownership, and creativity.

The use of Musical Things can promote an embodied approach by allowing children to experiment with different aspects of sound (NL), such as pitch, loudness, and timbre, through individual and collective movement. In doing so, children can engage in the different types of play as proposed by Ihamäkki and Heljakka [31], namely exploratory, constructive and creative play.

Consider a group of children. Each child has the envisaged musical thing (MusT). First, children individually explore how to modulate a soundwave through meaningful body movement (ESM, NL). For example, by horizontally shaking the MusT, they can modify the periodicity, and thus pitch: moving slowly to have a low tone, rapidly to have a higher tone; by vertically shaking, they can modify the amplitude and thus loudness: big vertical movement for a large amplitude and vice versa. Importantly, an inbuilt calibration system may take into account the abilities of each child interacting with the IoMusT (A & I).

When coupling MusTs per two, children can create a sound together (PSM): one child modulates periodicity, the other amplitude. Exploratory activities can be complemented with more guided exploration or even direct instruction activities involving, for example, the imitation of tones. Such tones could be provided by the teacher to introduce a scale, followed by the imitation of a melody. Or they can be provided by a peer, and next combined into their own melody (NL).

Once children have individually explored the modulation of tones, they can start combining their self-created sounds and learn about how this changes the sound (PSM). Note that wirelessly coupling the MusT to a screen or using an inbuilt display might also provide the children with visual feedback on how sinewaves change through their actions.

B. Scenario 2: Timing and Rhythm

A sense of timing and the ability to synchronize and (re)produce rhythms within a certain tempo are important elements of joint music-making. Integrating connected MusTs in the classroom can address these elements and support their development.

Imagine a group of children freely walking around (ESM), shaking the MusT in sync with each step they take, thus triggering a sound (they have created before). Children who are not able to walk around, can still join and shake the IoMusT (A & I). Next, they are invited to find a common tempo (PSM). As soon as group synchronisation improves, a backing track might be added based on the detected common tempo. This can be done in different ways, for example, by starting with some additional noise that decreases when synchronisation improves or by adding more instruments in the backtrack. At some point, the children's engagement within a certain tempo might be disrupted, inviting them to suddenly start walking much slower and find a (slow) common tempo again.

New tasks can be given once the children have developed confidence in walking and stepping together. For example, some children might only trigger a sound on the first and third of four beats, while others trigger a sound on the second and fourth beat. To learn about meter, loudness can be added as a parameter. The first group might be asked to play louder (shake the MusT harder) on the first than on the third beat, while the other group is asked to always play softer than the third beat (shake less). In this way, the children experience the hierarchy of beats through body movement (ESM) and create together a specific pattern (PSM).

C. Scenario 3: Harmony

Harmony is an essential element of music that provides richness and depth to a melody. To help children understand and experiment with harmony, the use of MusT can be beneficial.

A first element in learning about harmony could be learning about dissonance and consonance, both playing a vital role in making music emotionally meaningful by providing a sense of variety and motion, tension and resolution.

Imagine a group of children walking around in the classroom. When two children are close to each other, the MusTs are automatically activated and produce a note that is previously assigned to each MusT. In this way, and especially by "meeting" different notes, children can experience how two notes interact and how the resulting experience can be different in terms of (dis)agreeableness. In a next phase, children can be invited to "meet" in groups of three or four. In this way, not only can chords be introduced, but children can also learn how an original dyadic dissonance can change when notes are added. For example, while C and D might sound dissonant, adding F and A makes a beautiful seventh chord. All this is possible thanks to the mediation of MusTs equipped with the ability to identify each other and automatically configure themselves.

D. Scenario 4: Remote activities

Each of the above-described scenarios can be translated into online activities. Evidently, some aspects need to be adapted when turning applications from co-located to remote settings. For example, walking in the classroom might be omitted as it may interfere with online interaction. However, locomotor activities might be replaced by other physical interactions with the IoMusT and as such maintain the embodied nature of using the IoMusT.

While classroom activities might focus more on sound outputs in relation to gestures, in an online music educational scenario it might be more beneficial to use an interface that provides visualizations. Take the example of the sine waves (Scenario 1). This could be easily visualized in a shared online environment. Note that, while manipulating sound waves could be easily done with a mouse(pad), the IoT enables a more bodily engagement and, as such, aligns with the approach promoted by an Embodied Music Pedagogy. Moreover, research has shown that users, especially children, prefer such gesture-based interfaces as they are deemed as being more fun (e.g., [71]).

Similarly, the extent to which users synchronize (Scenario 2) might be visually represented. For example, each user could be represented by a specific geometrical figure, e.g., a square. The better users synchronise, the closer they move together until they all merge into each other. Alternatively, different users may be represented by different visual objects, while synchronising to a given stimulus. For each user, the degree of synchronisation is represented by the transparency (low sync)/opacity (high sync) of the object. Instead of using visualisation, feedback on synchronisation might be provided using vibrotactile feedback. This type of feedback is increasingly used in music learning (e.g., [72], [73]). However, to our knowledge, it has not been implemented in a remote music educational context. We believe this could be a promising avenue to explore new techniques for embodied experiences of remote togetherness, considering, for example, the work of Shafiqul Islam and Lim on vibrotactile feedback in virtual motor learning [74]. Especially since, in remote learning, the absence of physical presence, non-verbal cues, and tactile approaches in online lessons may affect learning, engagement, and motivation [75]).

Regarding Scenario 3, users may navigate through a virtual room (cf. Minecraft) by using the orientation of their IoMusT, in view of meeting others. When close to each other, the specific sound output is activated in a similar way as described in Scenario 3.

VI. Conclusions

This paper presented a framework for the design and didactic implementation of IoMusT-based pedagogical applications.

We described a set of scenarios that illustrate how our vision can be applied in practice.

To date, research on pedagogical activities in the IoMusT have remarkably received less attention compared to other kinds of technology-supported musical activities such as performance or rehearsals. The present study aimed at contrasting this trend and at providing a new perspective that addresses the children as musical stakeholders in the IoMusT.

The proposed framework addressed some fundamental ethical issues, related to privacy and security as well as accessibility and inclusiveness. Nevertheless, other ethical dimensions can be considered (e.g., sustainability). The ongoing efforts on researching ethical standards for the IoMusT (see [76]) are also relevant to IoMusT applications targeting children.

It is the authors' hope that the present work could inspire practitioners and developers in focusing on the design, development and evaluation of IoMusT technologies targeting children.

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