AN INCLUSIVE AND ACCESSIBLE MUSIC INSTRUMENT PROTOTYPE AND ITS LEARNING METHOD

V. Faschi, F. Avanzini, L.A. Ludovico

University of Milan (ITALY)

Abstract

This paper presents the design and pedagogical framework of an Inclusive MIDI Controller, an accessible digital musical instrument (ADMI) developed to support users with diverse physical and cognitive abilities. The system integrates customizable hardware and software components, enabling interaction through various input devices such as joysticks, expanded keyboards, and eye trackers. Emphasizing universal design principles, the controller facilitates expressive music-making while remaining adaptable to individual needs. The paper also proposes a corresponding learning method that supports skill development, creative engagement, and therapeutic outcomes. This approach aims to make music education more inclusive, empowering all users to participate meaningfully in musical activities.

Keywords: Technology, Accessibility, Inclusivity, Music Education.

1 INTRODUCTION

Music is a universal language that transcends cultural and personal barriers, fostering creativity, expression, and social connection. However, not everyone has equal access to music-making due to physical, cognitive, or economic limitations. Ensuring inclusion in music means providing accessible tools, technologies, and methodologies that enable people of all abilities to participate in musical activities. This is particularly crucial in education, where adaptive solutions can empower young learners and individuals with disabilities, allowing them to engage meaningfully in performance and composition.

In this context, we present a virtual musical instrument that aims to be inclusive and accessible, thus falling into the category of Accessible Digital Musical Instrument (ADMI). This software tool has no requirements concerning the level of musical knowledge or ability of its users. The original idea was inspired by the need to find performance strategies for a user capable of moving only their fingers, toes, and eyes. Currently, this musical instrument can be played using a wide range of heterogeneous devices, including a mouse, an accessible mouse, a joystick, a computer keyboard, an expanded keyboard, simple buttons, a game controller, an eye tracker system, different kinds of micro-muscular sensors, and a musical controller.

Learning how to play this instrument not only nurtures creativity and technical skills but also promotes inclusivity, empowering students to explore music in ways that were previously unattainable. To this end, the paper proposes a teaching method to enable people with different types of disabilities to play the virtual instrument. The instrument offers settings to configure a user-tailored environment. The user, as well as a caregiver or educator, can choose how to map each connected controller onto musical events, such as triggering a note, a chord, a music sequence, a music sample, or launching events like turning a virtual score page.

The remainder of the paper is structured as follows: Section 2 discusses the concepts of accessibility, usability, and inclusivity in the context of music technology. Section 3 explores the concept and scope of Accessible Digital Musical Instruments (ADMIs). Section 4 focuses on the role of music education in enabling meaningful engagement with virtual instruments. Section 5 presents the Inclusive MIDI Controller, detailing its design goals, system architecture, and interaction models. Section 6 highlights possible links between the already established learning theories and the learning method used with the Inclusive MIDI Controller. Section 7 frames the proposed learning method in such a context and discusses its characteristics. Finally, Section 8 concludes the paper and outlines future directions for research and development.

2 ACCESSIBILITY, USABILITY, AND INCLUSIVITY IN MUSIC TECHNOLOGY

Accessibility refers to an individual's ability to access, navigate, interpret, and interact with various environments, physical, digital, or conceptual. In the context of computer applications, accessibility poses specific challenges. Many software systems are designed with implicit assumptions: users are expected to read and interpret visual information, type using a standard keyboard, interact with a mouse, and respond to audio cues. These assumptions often exclude users with physical, sensory, or cognitive impairments, making even widely used applications partially or completely inaccessible.

This concern extends to musical tools and interfaces, where accessibility is equally crucial. Engaging with music, whether by listening, composing, or performing, has well-documented cognitive and emotional benefits, serving as both a source of joy and a powerful form of non-verbal communication. Yet, many digital musical instruments and platforms remain inaccessible to users with disabilities due to design limitations, specialized requirements, or high costs driven by niche markets and limited commercial interest.

Closely tied to accessibility is the concept of **usability**, which refers to how effectively a system meets its functional requirements. While usability focuses on task performance and efficiency, it is sometimes conflated with accessibility. Some scholars argue that both terms reflect the broader principle of *person-environment fit*, especially when evaluated through task-based user interactions. A broader discussion of accessibility, usability, and universal design, which is a philosophy aiming to accommodate the widest range of users, is offered in the work of Iwarsson and Ståhl [1].

Another foundational concept is **inclusivity**, conceived as the commitment to equitable access and fair treatment across all demographic and ability groups, irrespective of physical abilities, race, gender, or cognitive conditions. Accessibility, usability, and inclusivity together form the three pillars of our design approach.

Information and communication technologies can play a transformative role in promoting social inclusion for individuals with disabilities. In music technology, accessible solutions can empower users to create and perform music using the physical or cognitive capabilities available to them. Unfortunately, truly inclusive and affordable musical tools remain scarce, often limited by commercial viability and technological complexity.

3 ACCESSIBLE DIGITAL MUSICAL INSTRUMENTS

Accessible Digital Musical Instruments (ADMIs) are electronic or software-based instruments specifically designed or adapted to accommodate users with diverse physical, sensory, or cognitive abilities. Unlike conventional digital musical instruments, which often assume standard input modalities such as two-handed keyboard use or fine motor control, ADMIs prioritize universal design principles, enabling interaction through customized hardware interfaces, alternative controllers, and assistive technologies.

The core goal of ADMIs is to ensure that musical expression is not limited by a user's physical or cognitive constraints. These instruments can range from mainstream tools modified for accessibility (e.g., screen-reader-compatible digital audio workstations) to purpose-built solutions that use gaze tracking, switch-based control, or gesture recognition to produce sound. In this respect, ADMIs operate not only as musical tools but also as assistive technologies, bridging the gap between individual ability and expressive potential.

In the scientific literature [2], ADMIs can be defined as musical interfaces developed with the explicit intent of being accessible to individuals with impairments, thus highlighting the importance of inclusivity from the earliest design stages. Rather than retrofitting existing instruments, ADMIs often emerge from interdisciplinary collaborations that involve musicians, technologists, educators, and end users. This user-centered approach ensures that both musical quality and accessibility are preserved.

The scope of ADMIs extends across multiple domains:

- Education: ADMIs enable inclusive music education by allowing students with disabilities to participate in individual and group performance, composition, and improvisation.
- Therapy and rehabilitation: These instruments support cognitive and motor development, offering therapeutic benefits for individuals recovering from neurological injuries or managing degenerative conditions.

- Professional performance: Some ADMIs are designed with high levels of control and expressivity, suitable for professional musicians with disabilities performing on stage or in studios.

Since the subject of ADMIs' design analysis is still overlooked, Davanzo and Avanzini [10] have proposed a formal tool to explore the main design aspects of ADMIs based on Dimension Space Analysis, which is a well-established methodology in the field of new interfaces for musical expression.

4 THE ROLE OF MUSIC EDUCATION

As clarified in the previous sections, our goal is to eliminate barriers to musical expression for users with disabilities. However, accessibility alone is not sufficient. To foster meaningful engagement with a virtual musical instrument, music education plays a pivotal role.

First, as with any traditional instrument, proficiency in using digital or assistive instruments requires structured learning and regular practice. A virtual instrument, no matter how intuitive or accessible, still demands a process of familiarization, skill development, and refinement of technique in order to fully realize its expressive potential [3,4].

Secondly, education supports user motivation by fostering intentionality in musical creation [5,6,7]. Without a pedagogical framework, interaction with sound-generating interfaces may remain at the level of random event triggering. In contrast, an educational approach nurtures deliberate, goal-oriented artistic expression. This not only enhances the creative capability of the user but also affirms their role as an active and conscious music-maker, rather than a passive participant in sound production.

Moreover, music education has well-documented therapeutic benefits [8,9]. For individuals with physical impairments, engaging with music through adapted instruments can promote motor coordination, spatial awareness, and fine motor control. For users with cognitive disabilities, music activities support memory, attention, and emotional regulation. The act of learning and performing music also contributes to a sense of achievement and self-esteem, which are essential for personal development and social integration.

Beyond these benefits, musical learning environments also provide a social context for interaction, collaboration, and inclusion. Music-making often takes place in group settings (e.g., ensembles, classrooms, and workshops) where individuals of diverse abilities can share experiences and co-create. This collective engagement reinforces the inclusive goals of accessible instrument design, promoting empathy, mutual support, and the breaking down of social barriers.

Ultimately, an accessible musical instrument must be complemented by a dedicated learning method, tailored to the specific needs, goals, and abilities of each user. The design of such methods must consider adaptive teaching strategies, customizable interfaces, and multimodal feedback systems. In the presented work, we therefore advocate not only for accessible tools but also for accessible and inclusive pedagogies, recognizing that the full potential of music technology is only realized when paired with meaningful educational practices. These two aspects, namely a suitable ADMI and the corresponding learning and teaching method, will be addressed in the following sections.

5 INCLUSIVE MIDI CONTROLLER

The aforementioned initiative focuses on a software and hardware ecosystem called the *Inclusive MIDI Controller*, designed to accommodate diverse interaction needs. The goal is to develop a scalable, user-centered solution that adapts to everyone's abilities, including integration with familiar input devices and support for advanced MIDI 2.0 features such as automatic device discovery and configuration.

5.1 Design Goals and Requirements

The Inclusive MIDI Controller was designed to accommodate users with a range of physical and cognitive impairments, including quadriplegia, blindness, and color vision deficiencies. The goal is to eliminate barriers to music creation by enabling users to interact with the software through familiar or personally adapted hardware, such as eye trackers, joysticks, screen readers, braille displays, or expanded keyboards.

This project is grounded in the principles of universal design and multimodal interaction. It allows users to personalize the interface and control mappings to match their abilities. The software is designed to be independent of musical expertise and supports creative expression for all, regardless of impairment.

The system supports cross-platform deployment (macOS and Windows) and is compatible with a broad range of input devices (keyboard, mouse, joystick, gamepad, eye tracker). It aims for hardware abstraction, allowing MIDI message generation through any user-preferred device, minimizing reliance on specialized or costly equipment.

5.2 System Architecture and Implementation

The Inclusive MIDI Controller has been developed with a focus on flexibility, cross-platform compatibility, and broad hardware support to meet the diverse needs of users with varying abilities. Its architecture is shown in Figure 1 and includes software and hardware components.

The diagram illustrates the proposed modular hardware/software ecosystem. The architecture has been designed to integrate a wide variety of input devices, communication protocols, and a software environment for sound processing, allowing users to engage with music in multiple, customizable ways.

First, the system incorporates an array of input devices, each offering a different mode of interaction. These include traditional peripherals like a computer keyboard and mouse, which may serve for configuration or basic control tasks. However, more specialized devices play a central role in user interaction. For instance, a set of buttons or a gamepad provides tactile feedback and straightforward mapping to musical events, making them suitable for both novices and users with limited mobility. Similarly, the presence of a wireless motion detector enables gestural control, translating body movements into expressive musical parameters, adding a performative dimension to interaction. Of particular relevance to accessibility is the inclusion of an eye tracker, which allows users to trigger musical actions using gaze alone. This hands-free modality is especially valuable for individuals with severe motor impairments.

All these input devices are connected, directly or wirelessly, to a hub, which acts as the central point for data aggregation and routing. The hub ensures that signals from heterogeneous sources are correctly collected and forwarded, serving as the system's logistical backbone. Once the raw input is gathered, it must be translated into a format that the music software can understand. This is accomplished using standard communication protocols, notably MIDI (Musical Instrument Digital Interface) and OSC (Open Sound Control). These protocols carry the input data, now encoded as meaningful control messages, toward the software environment.

At its core, the software leverages the JUCE framework, an open-source C++ platform widely adopted in the audio software development community. JUCE was selected for its robust support for MIDI, low-latency audio processing, and seamless deployment on both macOS and Windows. These characteristics ensure that the software can function efficiently across common computing environments, lowering barriers to adoption and ensuring consistency in user experience. The software is designed as a standalone desktop application, offering a visually intuitive interface composed of customizable “pads”. Each pad can be configured to perform specific musical functions (such as triggering MIDI notes, chords, or sequences) and can be activated using a variety of input methods. The user interface supports between two and twelve pads per screen and includes auxiliary pads accessible only via keyboard shortcuts. This level of configurability ensures that the interface can be simplified or expanded according to user preference and capability.

At the receiving end of this pipeline lies the Digital Audio Workstation (DAW), the software engine responsible for generating and manipulating sound. The DAW interprets the incoming control messages and executes actions accordingly, whether it's playing back samples, synthesizing sounds in real time, adjusting parameters like pitch or tempo, or applying audio effects. Depending on how the system is configured, each input device may control different aspects of the DAW's behavior, offering a highly adaptable interaction model.

A key architectural choice in the Inclusive MIDI Controller is its device-agnostic input abstraction. The software is capable of receiving input from standard devices as well as assistive technologies. Inputs are mapped onto MIDI or OSC events. This abstraction layer allows users to control the software using hardware they are already comfortable with, minimizing the need for new learning or adaptation. By combining multiple input modalities with standardized communication protocols and a versatile sound processing environment, it creates a flexible platform for music creation and performance. Moreover, its design accommodates users with a wide range of physical abilities, underscoring its potential in inclusive music education and accessible creative expression.

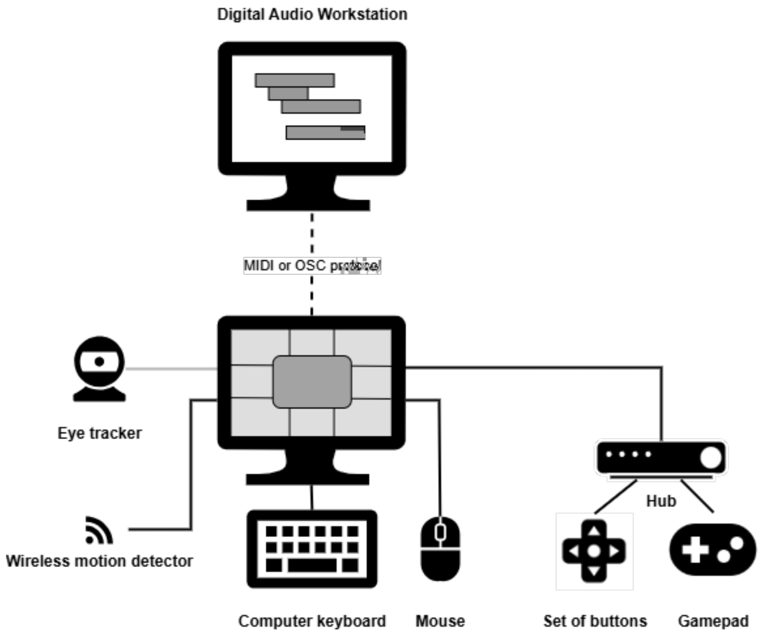

Figure 1. Scheme of the Inclusive MIDI Controller ecosystem.

5.3 Interaction Models and Control Mapping

The Inclusive MIDI Controller was conceived with the principle that interaction with music technology should not be bound by a user's physical abilities or by specific hardware. At the heart of its design is a flexible interaction model that supports a variety of input methods and control mappings, making musical expression accessible to users with diverse capabilities and preferences.

A defining feature of the system is its support for multiple input devices, each offering unique musical affordances. Traditional devices such as keyboards and mice are fully compatible, but the true strength of the platform lies in its ability to integrate alternative and assistive hardware. For instance, users can interact with the software through eye-tracking systems, joystick-based mice, expanded keyboards with physical keyguards, and braille displays and screen readers. Even extremely simplified input devices, such as push-button interfaces, can be profitably integrated [11]. These devices enable users with limited mobility or sensory impairments to engage with musical tasks in a way that aligns with their physical and cognitive comfort zones.

Each input device can be mapped to a variety of musical functions through a highly configurable pad-based interface. These virtual pads serve as the primary interaction points, and each can be assigned one of several actions: triggering individual MIDI notes, playing chords, launching short MIDI sequences, sending control change messages, or navigating between interface pages. The activation of these pads can be customized to match the user's interaction style. As an example, a pad can be set to "trigger" a sound with a single gesture, "hold" a note as long as the interaction persists, or "latch" a sound on until toggled off by a second action. This flexibility allows the system to accommodate everything from single-switch input to continuous control.

Specific mappings provide concrete examples of the system's adaptability. One user might use an eye tracker to gaze at a colored pad on the screen, thereby selecting a note or chord to be played. Another user could operate a joystick to hover over a button, triggering a percussion sample. A visually impaired user, supported by a screen reader, might rely on keyboard shortcuts to navigate between pads and control MIDI sequences. The mappings are not fixed; rather, they can be tailored extensively to match the needs and preferences of each user.

Beyond individual mappings, the system also supports adaptive configurations that take into account the user's specific abilities. As an example, users with motor impairments can limit the number of visible pads to simplify the interface or assign repeatable actions to shortcuts to reduce the physical effort needed to perform repeated gestures. The ability to define both primary and secondary triggers, such as using both mouse input and a keyboard shortcut, adds another layer of redundancy and flexibility, which is especially beneficial for users with fluctuating physical control. For users with limited mobility but preserved finger control, finger-only interaction is enabled through joystick-enabled mice or expanded keyboards, allowing precise input with minimal movement. Those with more severe motor impairments can rely on eye-only interaction, where eye-tracking devices are used to trigger on-screen buttons, enabling full control through gaze alone. For individuals who are blind or visually impaired, the system integrates tactile and audio feedback, supporting screen readers and braille displays to facilitate non-visual navigation and interaction. Additionally, users with color vision deficiencies benefit from an interface designed with color-blind accessibility in mind, ensuring that information is conveyed through multiple visual cues beyond color alone.

The inclusivity of the system is further demonstrated through real-world usage testing. During observational testing [12], users with varying impairments engaged with the software using their own assistive tools. A participant with quadriplegia successfully used a joystick-based mouse and an adapted keyboard to perform musical actions. Another user, who is blind, interacted with the system using a braille display and screen reader, though the test also revealed areas needing improvement, such as the accessibility of drop-down menus. These usage cases illustrate both the versatility and the evolving nature of the system, as feedback from diverse users directly informs future development.

6 THE LEARNING METHOD AND ITS THEORETICAL FOUNDATIONS

Mastering an articulated environment such as the Inclusive MIDI Controller requires the design and application of a suitable learning method.

A foundational principle is experiential learning, as articulated by David Kolb [13]. This model emphasizes the importance of learning through direct experience, followed by reflection, abstraction, and active experimentation. The Inclusive MIDI Controller encourages this cyclical process by allowing users to interact hands-on with sound and interface elements, reflect on outcomes, and iteratively refine their technique. This aligns well with the concept of learning by doing, where knowledge is constructed through active engagement rather than passive reception.

Closely related is the constructivist perspective, prominently advanced by Piaget and Vygotsky [14], which sees learners as active agents who build understanding through exploration and manipulation of their environment. The system’s customizable interface and multimodal design support this perspective by allowing users to construct their own pathways to musical expression, using hardware and control mappings suited to their abilities.

Vygotsky’s concept of the Zone of Proximal Development (ZPD) is particularly relevant in this context [15]. It suggests that optimal learning occurs when learners are guided through tasks that lie just beyond their current competence, achievable with support from more knowledgeable others. In practice, this means that caregivers and educators play a crucial role—not only in configuring the system but also in scaffolding the user’s progress by adjusting complexity and offering encouragement.

Maintaining motivation and engagement over time is critical. Here, Flow Theory, introduced by Mihaly Csikszentmihalyi, offers a useful framework [16]. Flow describes a psychological state in which learners become deeply immersed in an activity, balancing challenge with skill level. The Inclusive MIDI Controller supports this by enabling users to set personal goals, gradually increase complexity, and receive immediate, meaningful feedback, all of which contribute to a rewarding and immersive experience. Importantly, avoiding frustration is a key concern in accessible learning environments. Thus, the system’s adaptability allows users to work within their comfort zone while still experiencing the satisfaction of progress and achievement.

Learning with the Inclusive MIDI Controller also takes place in situated and social contexts, particularly during workshops or ensemble sessions. Drawing from Situated Learning Theory by Lave and Wenger [17], the system fosters authentic musical experiences where users develop skills by participating in meaningful activities alongside peers, educators, or therapists. This social engagement reinforces not only technical skills but also emotional connection and a sense of belonging.

Incorporating multimodal learning strategies further strengthens the pedagogical value of the system. Users engage auditory, visual, and tactile modalities simultaneously, enhancing retention and comprehension. This is particularly important for learners with sensory impairments who rely on alternative input and output channels.

Finally, the design of the learning method draws on Self-Determination Theory by Deci and Ryan [18], which emphasizes the importance of autonomy, competence, and relatedness in fostering intrinsic motivation. By allowing users to personalize their interface, set their own musical goals, and collaborate with others, the system promotes a sense of control and purpose in the learning process.

The proposed learning method, strictly connected to the features of the Inclusive MIDI Controller and developed simultaneously, takes inspiration from the above-mentioned theories. It aims to allow any user to perform pieces from the pop music repertoire, promoting the specific abilities of each participant. The final goal is the realization of a good-level live performance, potentially involving both impaired and non-impaired musicians. By "good-level" performance, we refer to a standard of execution that, while not necessarily reaching professional or concert-level expectations, clearly exceeds those of a casual or purely amateur performance. This level implies a degree of musical competence and commitment: participating musicians are expected to practice their instruments regularly, attend rehearsals, and develop ensemble cohesion. The aim is to deliver a performance that is technically accurate, musically expressive, and suitable for presentation in public contexts.

Before starting a new project, the music educator interviews each participant. The interview always takes place, even if the candidate performers have cognitive disabilities or are unable to communicate verbally. This step is essential to let the music educator understand the motor and cognitive abilities of the participants and, consequently, select the most appropriate repertoire and choose the best musical instruments or sensors to realize the performance. The key points of the interview concern the predisposition to use headphones/earphones or not, the ability to keep the beat and distinguish colors and numbers, the use of standard or specialized screens and keyboards, and the previous knowledge of accessible musical instruments or sensors.

To allow both professional musicians (with or without disabilities) and less experienced users (with or without disabilities) to play together, the use of a metronome is considered essential. Beat information is conveyed to musicians in the most suitable way, depending on their abilities.

Moreover, this kind of mixed ensemble, embracing traditional instruments, ADMIs, and sensors, requires special attention to the music arrangement. For this reason, the music educator has to prepare the parts to assign to each musician. One of the principles of the method is to never assign the same part to both impaired and non-impaired musicians. This would make it easier to compensate for shortcomings and conceal inaccuracies, but at the expense of the method’s core objectives.

7 DISCUSSION

While the Inclusive MIDI Controller has been engineered to remove technological and physical barriers, its successful adoption still depends on structured learning and ongoing practice, just like with any traditional musical instrument. Accessibility alone does not guarantee musical expression: users must be guided through a learning journey that enables them to make intentional, expressive use of the system’s capabilities.

Learning to play this instrument involves more than understanding which input triggers which sound. It requires developing familiarity with the interface, refining motor gestures, and progressively mastering the musical language enabled by the system. This underscores the importance of a pedagogical framework that supports both technical skill development and creative exploration.

In inclusive music-making scenarios, however, the emotional and motivational dimensions of learning are particularly critical. Avoiding frustration is a key pedagogical priority: users may be dealing not only with learning a new tool but also with navigating their own physical or cognitive limitations. A well-designed learning method must therefore be sensitive to fatigue, attention span, and each learner’s unique pace and preferences.

At the same time, challenge remains an essential element of the experience. Setting achievable goals and progressively increasing difficulty can help maintain engagement and promote a sense of accomplishment. In some cases, this challenge extends beyond music to a rehabilitative context: learning to operate the controller can support the recovery or enhancement of motor skills, offering therapeutic benefits alongside artistic ones. As an example, repeated practice in using a joystick or eye-tracking interface may contribute to improved coordination or stamina.

Caregivers and educators play a vital role in this process. They act not only as facilitators but as co-learners, adapting the system’s configuration and learning objectives in response to the user’s evolving needs. Their presence ensures that the musical journey remains inclusive, supportive, and personalized.

The learning path typically evolves through progressive steps: from basic interaction with the system (such as triggering a single note) to more complex activities, including improvisation, composition, or ensemble play. The customizable nature of the interface allows each user to follow a trajectory aligned with their abilities and interests.

8 CONCLUSION AND FUTURE WORK

In this paper, we described the Inclusive MIDI Controller, which is a versatile and accessible digital musical instrument designed to enable individuals of all abilities to engage in music creation and learning. It emphasizes inclusivity by offering adaptable interfaces and personalized configurations that accommodate various physical and cognitive needs. The learning method associated with the Inclusive MIDI Controller promotes collaborative, experiential, and student-centered approaches, leveraging creative expression to enhance motivation and skill development. Together, the Inclusive MIDI Controller and its educational framework foster an inclusive environment where music becomes a tool for empowerment and social participation.

Future developments will aim to broaden the spectrum of devices compatible with the Inclusive MIDI Controller, enhance its real-time adaptability and the MIDI 2.0 communication, and carry out user studies to assess its effectiveness across diverse populations. Furthermore, deeper integration with assistive technologies, including speech synthesis, haptic feedback, and eye-tracking, will be pursued to further improve accessibility and foster greater inclusivity.

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