Examining Temporal Trends and Design Goals of Digital Music Instruments for Education in NIME: A Proposed Taxonomy

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ABSTRACT

This paper presents an overview of the design principles behind Digital Music Instruments (DMIs) for education across all editions of the International Conference on New Interfaces for Music Expression (NIME). We compiled a comprehensive catalogue of over hundred DMIs with varying degrees of applicability in the educational practice. Each catalogue entry is annotated according to a proposed taxonomy for DMIs for education, rooted in the mechanics of control, mapping and feedback of an interactive music system, along with the required expertise of target user groups and the instrument learning curve. Global statistics unpack underlying trends and design goals across the chronological period of the NIME conference. In recent years, we note a growing number of DMIs targeting non-experts and with reduced requirements in terms of expertise. Stemming from the identified trends, we discuss future challenges in the design of DMIs for education towards enhanced degrees of variation and unpredictability.

Author Keywords

NIME, Music Education, Pedagogy, DMI for Education, Design, Taxonomy

CCS Concepts

•**Applied computing** → **Arts and humanities;** Sound and music computing; •**Education** → *Interactive learning environments;*

1. INTRODUCTION

In Western societies, music is typically taught as a set of principles emerging from the common-practice tonal music period as systematized in the vast plethora of musical treatises [7, 13]. Typically, the journey commences with the study of multiple hierarchies such as scales, followed by the identification and building of intervals and prototypical chords. Once these constructs are mastered, the study of functional harmony is undertaken, which ultimately dictates pitch relations and harmonic motion. In this context, music education gives a significant primacy to discrete Western notation-based concepts of note and duration. Remaining dimensions, such as timbre and performance-driven attributes such as micro-timing are seen as secondary attributes [23].

Furthermore, music education is typically split into areas of specialization, such as genre (e.g., classical, pop and jazz) and sub-specialization areas such as music composition or performance. Together with the preceding observation on the predominance of the common-practice period, most musicians wind up learning instruments stemming from the orchestral period, and the musicianship is typically focused on a master-apprenticeship paradigm [16]. In this context, one of the main objectives of the instrumentalists practice routine is virtuosity [22], whose foundations ultimately promote high levels of technical and performative (i.e., staging) aptitude [5].

In light of the interdependence of music creation and technology, in which musical instruments not only constitute major pieces of technological mastery but are also seminal for the development of musical expression [18], we aim to enlighten the disruptive value of Digital Musical Instruments (DMIs) in promoting new pedagogic approaches [17]. DMIs expand the traditional Western orchestral instruments and challenge the musical practice towards new corporeality, materiality, control and feedback [12]. In this context, we provide a comprehensive catalogue of DMIs for education in all editions of the New Interfaces for Musical Expression (NIME) conference, a privileged venue for the DMIs community. The catalogue is available online at: `https://sites.google.com/view/dmicatalogue`. Each DMI entry in the catalogue is classified according to a proposed taxonomy. Global statistics from our catalogue aim to ultimately unpack the trends and goals of DMIs design and shed light on the paradigms of the educational practice they promote.

The remainder of the paper is organized as follows. Section 2 describes the methodological approach adopted to select the DMIs included in the proposed catalogue and details the dimensions of a taxonomy for classifying DMIs for education. Section 3 provides an overview of trends across the DMI catalogue to support the identification of the design goals of DMIs for music education. Finally, Section 4 discusses future directions and new trends of DMI for music education.

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2. A CATALOGUE OF DMI FOR EDUCATION IN THE NIME CONFERENCE

Figure 1 shows the architecture of a typical DMI, which we understand as a system that features a control surface (also referred to as gesture or performance controller, input device or hardware interface) and a sound generation unit. As a result of our broad understanding of a DMI, multiple sonic materializations and application scenarios from installations to games or even sound toys are considered in the compiled catalogue of DMIs for education.

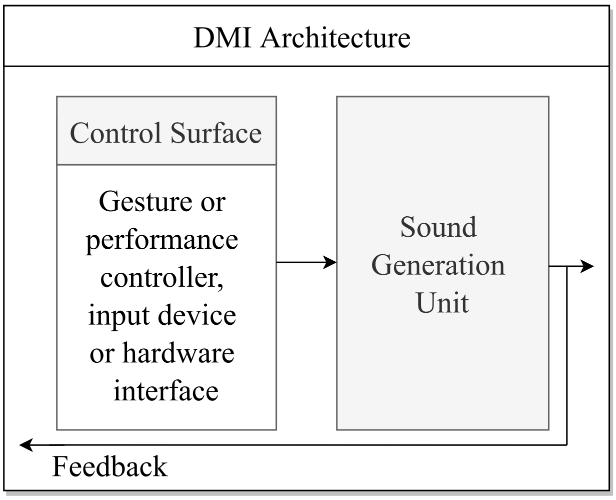

Figure 1: Architecture of a typical DMI system. Rectangular blocks denote the main component modules. Data flux is indicated by directional arrows.

Across the entire archive of the NIME proceedings ranging from the years 2001 to 2019, we identified and listed the DMIs motivated for, or supporting music education activities. To identify and select the DMIs for education to include in the catalogue, we adopted a twofold method. First, we browsed and identified the papers, including relevant keywords at the crossroads of musical practice and education. Table 1 lists the set of keywords adopted in the search process, which we split into two categories: areas of knowledge (e.g., study and training) and agents (e.g., student and novices). Second, from the resulting pool of papers, we did a thorough review of their contribution.

During the second phase of the review process, we extracted from each paper relevant information of the DMI. To this end, we propose a taxonomy of DMI for education adapted from Magnusson [10]. Broadly, it covers dimensions related to the system identification (*year, author, DMI name* and *degree of educational affiliation*); attributes from the interactive component modules [4, 19, 22] (*inter-actors, input controller, control parameters*, and *typology*) and information of the target users and musicianship (*required expertise* and *learning curve*). Figure 2 shows the taxonomy dimensions in detail.

2.1 DMI Identification

The DMI identification dimensions index a particular DMI in the catalogue by a unique interface name entry, author(s) names(s), and the year it features in the proceedings archives (which may not coincide with the year of the DMI creation). To this set of entries, the degree of educational affiliation was identified using a threefold categorization. The first and strongest tie, establishes an explicit link between

Table 1: Comprehensive list of keywords adopted in the initial selection stage of DMIs for education to include in the proposed catalogue.

Categories	Keywords
Areas of knowledge	Study, studies, course, teach, serious games, assist, assistive, education, pedagogy, pedagogical, training, classroom and learn.
Agents	Novice, children, expert, non-experts, non-musician, student, and beginner.

the DMI and education, as the result of being the primarily identified goal of the DMI in the paper. The second tie does not mention education as a primary area of the activity but states the potential of the DMI in this context. The third and weakest tie does not link the DMI to education, but a more attentive reading of the paper highlights some clear evidence of its potential in the area.

For example, in the first category, we can find *Wireless Sensor Interface and Gesture-Follower for Music Pedagogy* [1], a DMI gestural interface built to support music theory lessons in the classroom; *An Augmented Flute for Beginners*[6], a digital interface that shows multiple attributes of a flautist embouchure tracked from sensor-augmented flute; and *Haptic-Listening and the Classical Guitar*[11], a haptic-listening DMI that presents the listener with a representation of the vibrotactile feedback perceived by a classical guitarist during performance through the use of haptic stimulation.

In the second category, we can find *DrumTop* [21], a DMI that enables users to explore the creative potential of rhythmic interactions with everyday objects; *Piano Pedaller* [9], an interface for measuring, classifying, and Visualizing piano pedalling techniques; and, *Separating sound from source* [14], a hybrid violin with digitally automated pitch and tone correction through electrodynamic pickups, acoustic actuation and sonic transformations.

In the third category, we can find *Musician Maker* [3], a system that allows novice users to create expressive improvisational music; *Tok!* [8], a collaborative percussive instrument using mobile phones; and *Sound Control* [15], a software toolkit designed for children with disabilities to create custom digital musical interfaces.

2.2 Inter-actors, control and typology

The design of a DMI can be understood within the conceptual framework of an interactive music system, from which we borrow its component modules as dimensions of our taxonomy. In greater detail, for each DMI entry in the catalogue, we define the DMI inter-actors across the multiple combinations of human and computational agents; the interaction input control and parameters; and, finally, the typology of the system, ranging from sequenced to generative responses. Adopted dimensions are roughly based on [10], [19], [2] and [4].

Inter-actors define the agents involved in a performative ecology using a DMI. It can adopt three categories: one human performer and one computational system; multiple human performers and one computational system; and, finally, multiple human performers and multiple computational systems.

Interaction input control can assume three categories:

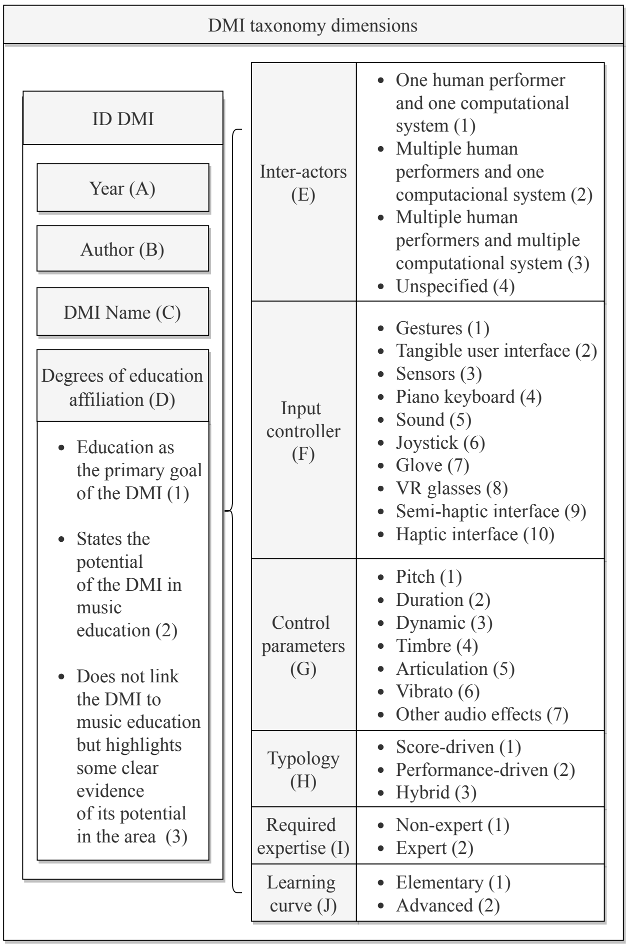

Figure 2: DMI taxonomy dimensions (grey blocks) and their categorical elements (white blocks). Values inside round brackets indicate the numerical symbol adopted in the catalogue to represent a particular category.

a physical controller, transparent embodied gestures, and audio. Physical controllers include, for example, gloves, joysticks, keyboards, gamepads or mobile phones. Transparent embodied gestures refer to interaction modalities which do not require a physical interface between the user and the computer to accomplish a particular action. Audio as an input controller denotes the use of audio attributes (e.g., pitch, amplitude and brightness) from sound-producing sources.

The control parameters dimension in our taxonomy is split into seven categories: pitch, duration, dynamics, tone colour (or timbre), articulation, vibrato, other audio effects. The list of control parameters includes both primary and secondary properties of music notation [23] as well as expressive performance qualities.

DMI typology can be defined as either score-driven, performance-driven, or hybrid. Score-driven DMIs incorporate predefined compositional structures in the style of a score following system [3]. Performance-driven DMIs has no pre-built knowledge or a priori compositional structure and relates to musical improvisation settings [8]. Hybrid DMI include the two previous strategies [20].

2.3 Target users: required expertise and learning curve

To characterize the DMI design considerations related to the target users, we adopt two dimensions in our taxonomy: required user expertise and the DMI learning curve. The required expertise is subdivided into two categories: non-experts, i.e., novice users with little to no knowledge of music theory and practice, and experts, i.e., users with advanced training in music theory and practice. This split characterizes the required initial experience to appropriate and/or manipulate a DMI interface expressively. Finally, degrees of training, proficiency or virtuosity detail the learning curve of the DMI to achieve expressive proficiency. We divide this dimension into two categories: elementary, which requires no musical or performative training, and advanced, which is intended for highly skilled virtuosos; thus, requiring much training.

3. ELICITING TRENDS AND GOALS ACROSS DMI DESIGN FOR EDUCATION

From the collected data in the catalogue, we computed global statistics, which we present and discuss in this section. Our main aim is to expose temporal trends across the data per dimension. Figure 3 provides an overall perspective on the number of DMIs for education across the temporal span of the NIME editions (on the horizontal X-axis). The blue vertical bars report the percentage of papers focusing on DMIs for education as a result of summing the three degrees of educational affiliation in our taxonomy. The red line indicates the percentage of DMIs with strong ties to education (i.e., the first category in our taxonomy). The regression lines from the data (in light blue and light red) expose an increase of attention on this topic over the years, namely from DMI with explicit ties with educational activities.

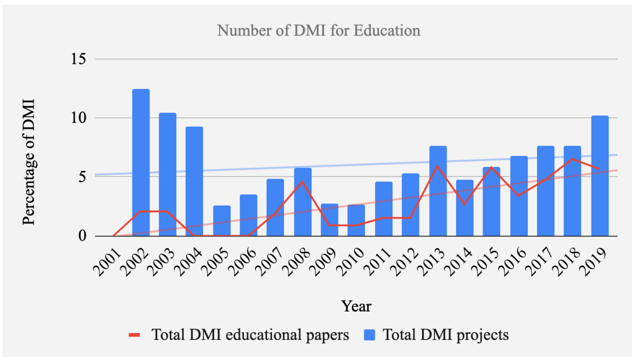

Figure 3: Number of DMIs for education across all editions of the NIME conference. Blue bars indicate all DMIs with links to the topic and red line those with a strong tie. Regression lines are shown for each category.

Figures 4 - 7 show stacked bar graphs, which compare the categories of each of the taxonomy dimensions across the DMIs for education in NIME. Two different graphs per dimension are adopted. On the left, we show a stacked graph with total counts per category across all NIME editions. On the right, we show the percentage of distribution per year.

Figure 4 shows the inter-actors dimension. A prominent DMI category is one human performer and one computational system, followed by multiple human performers and one computational system. These two categories emphasize DMIs design as a continuation the expressive modalities found in Western music practice and the role of the acoustic instruments, mostly designed for individual performance and orchestral ensembles.

Figure 5 shows the DMI typology dimension. Despite the predominance of score-driven DMIs, performance-driven DMIs have gained increased attention since 2010. This shift may be linked and explain the growing number of DMIs for improvisational practice.

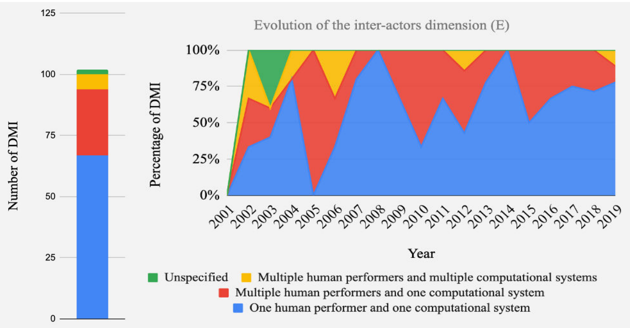

Figure 4: Educational DMI inter-actors dimension across the NIME conference editions. On the left, stacked graph representing the total number of DMIs. On the right, stacked graph showing the percentage distribution per year.

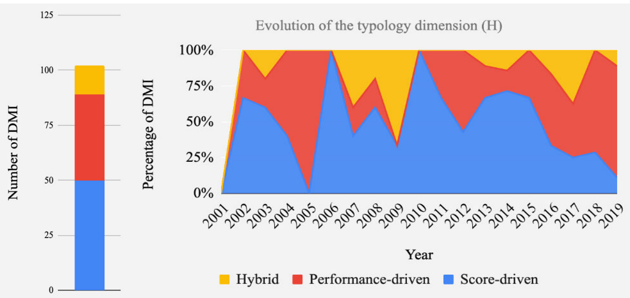

Figure 5: Educational DMI typology dimension across the NIME conference editions. On the left, stacked graph representing the total number of DMIs. On the right, stacked graph showing the percentage distribution per year.

Figures 6 and 7 show the target users dimensions of the DMIs for education, notably the degree of required expertise and the learning curve, respectively. We can observe a significant focus on DMIs for non-experts and an elementary degree of required expertise. This dimension of the taxonomy is the most expressive in distinguishing DMIs from Western orchestral instruments, as it denotes an increased focus on DMIs for novice users which promote immediate and expressive musical experiences. This trend can be understood in the context of the growing number of algorithmic methods for music creation that promote engaging experiences for users with very little musical training.

4. CONCLUSIONS AND FUTURE CHALLENGES

In this paper, we compiled a comprehensive catalogue of DMI for education across all editions of the NIME conference. Furthermore, we proposed a taxonomy for DMI

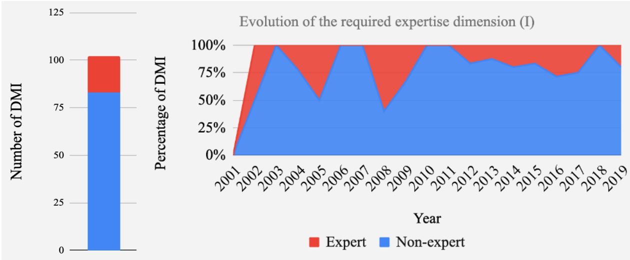

Figure 6: Educational DMI required expertise dimension across the NIME conference editions. On the left, stacked graph representing the total number of DMIs. On the right, stacked graph showing the percentage distribution per year.

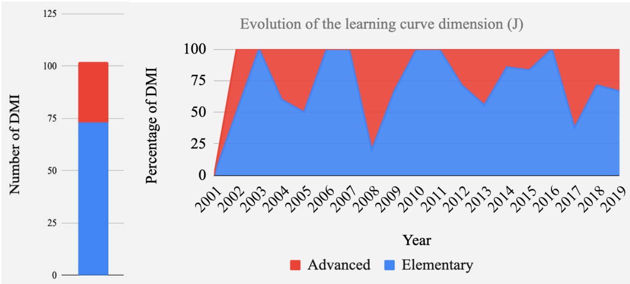

Figure 7: Educational DMI learning curve dimension across the NIME conference editions. On the left, stacked graph representing the total number of DMIs. On the right, stacked graph showing the percentage distribution per year.

based on dimensions from interactive music systems and target users and practices. Each DMI entry was characterized accordingly. From the catalogue, we computed global statistics which aim to unpack the trends and design goals of DMI, which we discuss in light of the traditional orchestral practice of Western instrumental music. The catalogue is available online as a CSV file to promote easy access to the collected data.

From the preliminary statistical analysis of the catalogue, we observe an increasing interest of DMI for education in recent years. A notable target on novice users without music theory and practice training suggests an effort in providing expressive musical experiences for this group of users. Moreover, it may be symptomatic of the changes across the range of pedagogical tools available and the market of musical toys and digital application for mobile handheld devices, such as smartphones. On the other hand, the elementary degree of required training observed across most DMIs place them in between musical toys and fleeting experiences, which may not prompt continuous investment on the part of the users.

Despite the large degree of affiliation observed in our analysis between current DMIs design and traditional Western instruments, DMIs have the potential to explore musical expression and practices beyond this scope. In combination with existing pedagogical strategies, existing DMIs enable the introduction of new topics of interest in musical curricula. First, they show high potential for motivating the study and practice of music due to its almost immediate results, which traditional orchestral instruments cannot attain. Second, their materialization is typically directed to the use of low-cost devices, such as smartphones, which we carry on a daily basis, enforcing high degrees of portability and adaptability to the needs and pace of individuals.

Third, they show great potential for the exploration of concrete sounds in designing soundscapes, rethinking local and global cultural heritage and even the promotion of diversity across cultural traditions from multi-instrument practices emulated via the digital domain. In this context, in light of the extensive list of DMIs, we believe that a stronger focus should be directed towards the study of pedagogical plans for their appropriation within music curricula.

DMIs can also be used to revisit the communication mediums in music performance and education beyond the physical, performative space settings. The identified growing DMI trend adopting multiple performers and a single interactive system can enable remote network performances. As such, music curricula can adhere to holistic approaches to an apprenticeship from musical manifestations.

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