Musical Interface Design: An Experience-oriented Framework

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ABSTRACT
This paper presents MINUET, a framework for musical interface design grounded in the experience of the player. MINUET aims to provide new perspectives on the design of musical interfaces, referred to as a general term that comprises digital musical instruments and interactive installations. The ultimate purpose is to reduce the complexity of the design space emphasizing the experience of the player. MINUET is structured as a design process consisting of two stages: goal and specifications. The reliability of MINUET is tested through a systematic comparison with the related work and through a case study. To this end, we present the design and prototyping of Hexagon, a new musical interface with learning purposes.

Keywords
Framework, DMIs, interactive installations, user experience

1. INTRODUCTION
For several years, NIME and related communities have been coping with the challenge of framing a design space for musical interfaces. Framing a design space serves the purposes of designers, providing them with concepts that systematize their thinking and stimulate thought [13]. It can inspire design, reveal potential problems [1], and act as a reference point for future studies on user experience [13].

A simple design space of musical interfaces can be described along a continuum that stretches from Digital Musical Instruments (DMIs) to interactive installations [4,31]. More articulated approaches have mainly focused on DMIs by differentiating, for example, among augmented traditional instruments, instrument-like controllers, instrument-inspired controllers and alternate controllers [19]. This categorization is device-oriented: while considering the similarity to traditional instruments and the technology featured in the controller, it fails to account for the profound variations affecting the experience of the player. As an example, suffice it to consider the difference between a violinist using an augmented bow [26] and a Reactable player [17].

The other pole of the design space defines interactive installations, i.e. those systems "that are only realized through a participant's actions, interpreted through computer software or electronics, and those actions do not require special training or talent to perform" [29]. Interactive installations have very different characters, scopes and goals and they usually emphasise the user experience rather than a set of musical activities performed on an instrument. Several installations allow visitors to inspect multimodal spaces or artifacts and provide them with aesthetic experiences (e.g. Iamascope [11] and PebbleBox [22]). Some works, instead, specialize in enabling visitors "to interactively operate on music content […] while listening" [7] (e.g. The Brain Opera [25], Sync'n'move [27] and The Music Room [20]). Other installations focus on thought stimulation, self-regulation support and behavior change by means of music (e.g. Sonic Cradle [28] and Piano Staircase). This concise review attests that (i) the design space of musical interfaces is complex, difficult to categorize and likely to be influenced by personal interpretation; (ii) the player's experience determines the goals and the challenges of both DMIs and interactive installations.

In this paper we aim at framing a conceptual understanding of musical interface design centered on the experience of the player. This framework is supposed to provide a model for reducing the complexity of the design space of different player experiences, ranging from Disklavier pianists to visitors of the Music Room [20]. The outcome of this work is MINUET (Musical INterfaces for User Experience Tracking), a design framework for the identification of the elements involved in musical interface design, which can help designers to position, shape and evaluate their systems. MINUET is a design process structured into two stages, following each other in a non-invertible sequence. The first stage analyzes the goals of the interface, and the second stage specifies how designers can actually achieve these goals.

MINUET can serve the following purposes: (i) reducing the complexity of the design space of musical interfaces; (ii) specifying a set of success criteria; and (iii) guiding evaluation procedures. Due to space constraints, we are only focusing on the first point in this paper, leaving the analysis of the other two points to our future works. To achieve this goal, we grounded MINUET on related work (Section 2) and delivered a design process to tackle the issue from the perspectives of designer goal and specifications (Section 3). The reliability of the framework is discussed by drawing parallels with existing research (Section 4) and by testing it with a case study (Section 5). The final part of the paper provides an insight into future works.

2. RELATED WORK
Over the last few years the investigation of the design space of musical interfaces has been arousing an increasing interest. Two meta-reviews have attempted to suggest how to catalogue these studies: [10] analyzes the different approaches to the definition, classification and modeling of DMIs, while [18] surveys the methodological approaches employed in the design of DMIs.

Most of the studies on the design space of musical interface restricted their investigation to DMIs. [15] tackles the challenge from the general perspective of the interaction modalities with musical instruments differentiating between instrumental (the musician has control over every aspect of the instrument), ornamental (the system has control) and conversational (shared control). Similarly, [16] centers the framework on the relation between player and instrument, discussing issues of balance (between complexity and simplicity), playability, learning curve and instrument efficiency. [24] and [14] suggest two frameworks theorizing about the type of possible gestures in this context. [24] distinguishes between intuitiveness and perceptibility of gestures, and between ergotic (gestures used to manipulate physical objects) and semiotic (gestures used to communicate meaningful information, such as thumb up). [14] analyses the strategies for mapping gestures onto synthesis parameters centered on cognitive modes (analytical vs. holistic). [30] narrows the analysis to the musical instruments that inspire long-term engagement and proposes seven heuristics that describe the qualities of these instruments: incrementality, complexity, immediacy, ownership, operational freedom, demonstrability and cooperation. [23] addresses the issue of DMI evaluation from the perspective of the different stakeholders (performers, composers, audience, manufacturers and designers).

Only a few studies, such as [4], broaden the scope of the design space of musical interfaces by considering also interactive installations. Birnbaum and colleagues base this design space on seven dimensions: required expertise, musical control, feedback modalities, degrees of freedom, inter-actors, distribution in space and role of sound [4]. [31] suggests taking inspiration from HCI techniques for the evaluation of control and usability of musical interfaces. In particular, this framework is based on learnability, explorability, feature controllability and timing controllability. Blaine and Fels [5] focus on collaborative musical experiences and propose seven primary dimensions to be borne in mind when designing: physical devices, type of interaction, learning curve, pathway to expertise, level of physicality between players, directed interaction and musical range. [9] presents a model for the design and evaluation of musical interfaces concentrating on the modality of interaction: the interface can employ a simple modality (visual or auditory), or multiple modalities by integrating simple modalities.

The contribution of these works towards a better understanding of the design space of musical interfaces is indisputable. Most of them, however, have apparently failed to convince the community to adopt any such frameworks. A possible reason is that the quality of a framework should be based on how it helps designers by stimulating creativity and allowing them to delve into the design process. Furthermore, the increasing number of interactive installations operating in the musical domain suggests that new research should be done in this area.

3. MINUET

MINUET offers a conceptual model for the understanding of the elements involved in musical interface design, providing a frame to bear on this complex design space. This frame can help designers (i) to position their work in a structured design space, (ii) to elaborate ideas and objectives when designing a new musical interface (iii) to guide the evaluation process. The idea is to tackle this challenge by clustering design elements from the point of view of the player's experience. Also, rather than providing a list of design metrics and heuristics, MINUET integrates a temporal dimension into its structure, consisting of two stages which can by no means inverted.

3.1 Method

MINUET results from a synthesis of the related work and concepts developed by the authors. The final structure has been developed over the course of several iterations, including a workshop attended by a selected group of three HCI researchers, a professional musician, and an interactive artist. At first, the authors identified the related work discussed in 2.1 by means of a meta-review process. Related work was primarily collected in the basis of on the references analyzed in [10,18], while remaining papers were chosen on the basis of their relevance to the topic. Next, the selected works were schematized in connection to the proposed dimensions (or heuristics) and to the related category of musical interface (DMIs and interactive installation). Later, we organized a one-day workshop: participants were encouraged to discuss affinities and connections among these works. The methodology adopted is affinity analysis [3]: guided by one of the authors, participants explored connections, similarities and differences among these works by using sticky notes and several A0 cardboards. They were then asked to propose and discuss a number of dimensions that could correctly cluster the associated design guidelines from the perspective of the experience of the user. From this iteration, three sets of concepts emerged: *Objective of Interaction*, *Constraint* and *Context*, that respectively answered to the questions: *what* the goal of the interface is, *how* this should be designed, *where* and *when* it should take place. The successive version of the model was rearranged by the authors, who redistributed the three sets of concepts into two stages of a design process: goal and specifications. This change was then analyzed and supported by some of the workshop participants. Lastly, a few minor modifications to the framework were made during the analysis of the case study, reported in this paper

3.2 Model

MINUET structures the designing of musical interfaces into a two-stage process: the first stage, **Goal**, describes the objectives of the interface, while the second stage, **Specifications**, help designing the interaction in order to fulfill these objectives (Figure 1). Each stage is composed of some entities that address design issues on a more pragmatic level. To model these entities we drew up inspiration from the influential work by [2], which defines a conceptual model for the design of interactive systems. The PACT framework helps designers to investigate the design process by means of a user-centered technique based on **People**, **Activities**, **Contexts** and **Technologies**. The four entities detail the objectives and the constraints of the interface, and are specified by a series of directly applicable design perspectives (the elements included in the inner circles in Figure 1).

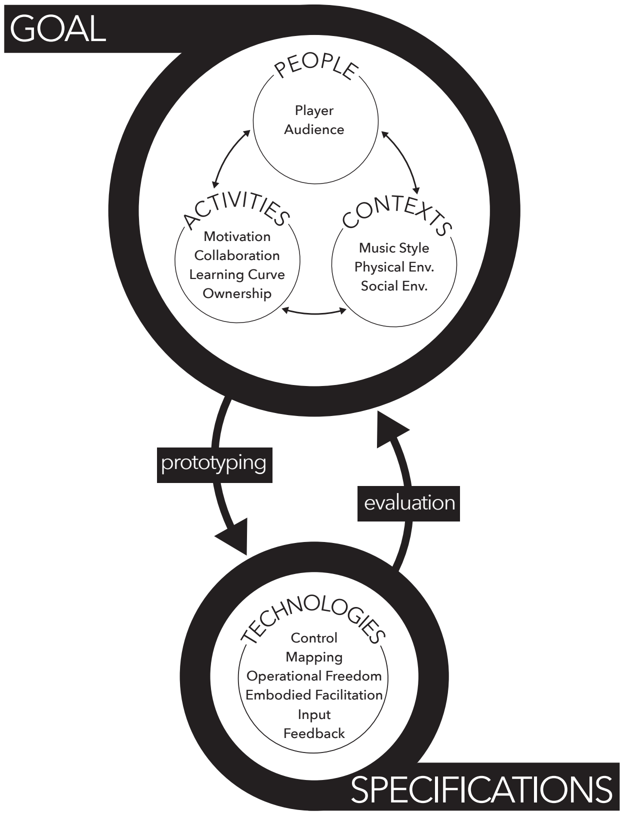

Figure 1. MINUET framework.

The design process starts from the analysis of the designer *goal*, which describes the purposes of interaction. This stage is articulated in three parts: **People,** identifying the end-user (*who*) **Activities,** specifying the kind of interactions the designer has in mind (*what*) and **Contexts** detailing the specifications of the environment (*where* and *when*). Once the interaction goals have been defined, designers can move on to the *Specifications* stage by prototyping the interface. This stage analyses *how* to design the interaction resembling the last entity of PACT framework, **Technologies.** Unlike Benyon's "Technologies", we focus on the identification of interaction requirements rather than considering hardware and software implementations. Lastly, designers can evaluate the proposed specifications by referring back to the original goal.

3.3 Goal

The first stage of MINUET frames a conceptual model of the interface goal, in the shape of a very high-level user story [8]. The related concepts guide designers to reflect upon the kind of experience they wish to offer. Players can use a musical interface for a number of reasons: to perform, to compose, to control or to learn music. The interface can provide players with a playful experience, stimulate creativity and convey a meditative experience; also, it can have an informative meaning, and it may or may not have educational purposes. In order to cope with the diversity of interactions, this design space is simplified detecting patterns and suggesting insights that can assist designers' reflections. In fact, they are invited to look at their goal through the lenses of People, Activities and Contexts. '*People'* looks at the designer's objectives from the viewpoint of the targeted category of players and from the role of the audience (*who*). '*Activities'* questions *what* the envisioned interaction is, by framing the type of musical interface. '*Contexts'* investigates the environment and the set-up of the interface (*where/when*). The relevance of these entities varies according to the nature and the goals of the interface and the priority scale has to be given by designers themselves.

3.3.1 People

This entity specifies the subjects who will engage with the interface, namely players and audience.

Player. A critical point when constructing specific experiences is to define the target user. The interface could address professional or amateur musicians, players that are quite familiar with music, or non-experts. An augmented bow can be designed to enhance the playing experience of professional cello players, or to ease access to the instrument to newcomers.

Audience. In interactive systems the audience may not perceive the interactions between the performer and the system, as they would do with traditional instruments [12]. Designers that intend to allow spectators to understand such interaction specifically target this issue. The intelligibility or the ambiguousness of the performance greatly depends on the performer's capability of showing others how action-reaction mechanisms work. In some interactive systems, spectators can also actively take part in music creation.

3.3.2 Activities

The objective of interaction can be considered from the lens of envisioned player activities. The associated concepts are: motivation, music style, learning curve, ownership and collaboration.

Motivation. This concept provides insights into the motivations of the players, analyzing the relevance of the sonic and musical medium with respect to the user experience. In interactive installations, sound often has an accessory goal, as it is supposed to guide the exploration of the environment. Vice versa, the creation or the manipulation of sounds is the primary goal of traditional DMIs and interactive sonification systems, in which users explore particular information conveyed into abstract musical form.

Learning curve. The learning curve provides information on the time required to gain skills with an interface and/or to understand how interaction works. Traditional complex interfaces requiring a significant investment of time should preferably allow high ceiling, as to ensure long-term engagement and enable players to develop skills, as it is the case with traditional instruments. By contrast, museum installations have to be experienced in a very short time, and therefore they must be able to reveal how they work within seconds. In this case the learning curve needs a low floor.

Ownership. Interfaces that specifically address the generation of creative artifacts should aim at the uniqueness of musical expression. When the musical output is a form of self-expression, the execution, the identification and the recognition of unique playing styles should then be supported [30]. By contrast, when the interaction is not centered on the actual production of a musical output, replicable outcomes are to be expected. Ownership can also refer to the way players interact with the interface if the system allows them to configure the interface according to their own wishes.

Collaboration. Musical activities can be carried out alone or in a social context. Designing collaborative experiences means considering awareness of others, and factors such as synchronization and coordination. Sometimes, musical interfaces can only be fully exploited in collaborative contexts: in these cases, specific efforts need to be made to ensure the expected social dynamics.

3.3.3 Contexts

Contexts consider the environment in which the interaction takes place, i.e. all those elements that can help the identification of the interaction goals. This entity may not be very important for traditional DMIs, yet it is particularly relevant for installations and collaborative interactive systems. The associated concepts (music style, physical environment and social environment), detail what makes an application unique in relation to similar works.

Music style. In novel musical interfaces sound is produced by the computer, so the associated musical style is not influenced by the acoustic features of the instrument as in traditional music. This feature opens up new horizons for designers, who can choose the music style that better suits their goals, irrespective of the nature of the device. Identifying a musical style is crucial when it comes to targeting a specific population. For instance, when confronted with a broad target population, designers should make use of a familiar music language, such as tonal music [20]. On the other hand, when targeting a community of experts or avant-garde musicians, the music itself can be experimental. Addressing a specific musical style genre can also be the primary objective of the interface (e.g. the musical controllers for electronic music such as Korg Kaossilator).

Physical environment. When reflecting on the goals of the interface, its own nature frames the importance of the space in which it is going to take place. While traditional controllers do not require a precise spatial configuration, it is important to consider the physical environment hosting the installation. Some installations are designed to be exhibited on the occasion of specific events while others are hosted by museums for long periods.

Social environment. The social context and the proximity between players mirror different kinds of interpersonal relations. Intimate experiences need a small, secluded space, while provocative installations can either be open to the greatest number of passers-by or force individuals to interact with an object on a one-on-one basis. Designers might want to draw the attention of museum visitors, or to arouse the interest of people and of the media into a specific social issue.

3.4 Specifications

The second stage of the design process collects the goal considered by the previous issue and reflects on the interaction constraints between the player(s) and the system. When designing for intuitive experiences the amount of interaction possibilities should be restricted, as to guarantee an easy access to the players. By contrast, musical controllers should enable players to manage a multitude of parameters, as to have full control on the generated music. Specifications must be considered according to the level of control and to the input and feedback modalities as well as to the presence of human facilitators that might result in a loss of operational freedom.

Control. The degree to which the player controls the music varies along a continuum which includes the different categories of interfaces. For the sake of convenience, though, we will discretize three categories: low, medium and high control. Low-level controllers provide control on each note or on specific sonic parameters, just like traditional instruments. They usually address an expert population, as they rely on musical notations that are unknown to non-experts. Mid-level controllers give access to higher musical structures at bar-level or score-level such as rhythmic pattern, melody direction, mode, musical processes and loops. Depending on their closeness to note-level, they might be more or less accessible to non–experts. High-level controllers operate outside the musical domain, so they are generally open to everybody but do not allow any subtle interaction with musical structures.

Mapping. The level of control influences the complexity of mapping strategies. Low-level controllers require a convergent mapping [14]: in order to produce a single pitch, a sequence of physical tasks needs to be performed just as playing a note on the guitar usually requires the synchronization of two or more fingers). Vice versa, in interfaces controlling high-level musical elements, a single *mediated* parameter affects many musical factors (divergent mapping [14]). For instance, controlling *mode* influences two lower-level musical parameter, i.e. harmonic and melodic intervals. Sometimes interface metaphors are needed to hide mask music complexity from the player's interaction space. Interface metaphors indeed "allow users to readily make inferences about how to operate unfamiliar user interfaces by mapping existing skills and knowledge from some familiar source domain" [32]. In this case, a divergent mapping is necessary: controlling the emotional character of a piece will influence several musical parameters (e.g. mode, tempo, melodic direction and volume).

Input. Players can interact with the musical interface through symbolic, para-linguistic, involuntary and subconscious modalities [6]. The production of sounds might require physical energy an ergotic gesture. Alternatively, players could interact on a semantic level, through visual, tactile or semiotic gestures.

Feedback. This concept focuses on the presence and the role of feedback modalities (auditory, visual, tactile, or kinesthetic [4]). Designers are invited to consider the effects related to different feedback modalities. Adding multi-sensorial feedback can augment the experience, but also distract a performer. In most cases, the visual feedback is an accessory factor but sometimes it can become the main focus of user experience [11].

Operational freedom. Operational freedom defines the potential of players to express a creative interaction with the system and the flexibility of the interaction. Designers seeking to stimulate creativity, improvisation and adaptation should envision flexible and constraint-free interactions, while educational or training-oriented interfaces are better achieved through rigid task-achievements procedures. A snare drum has rather limited interaction possibilities, but offers endless compositional options. Vice versa, The Music Room [20] does permit players to creatively interact with the system, but the musical control depends on the choice of the piece's emotional tone.

Embodied facilitation. Embodied facilitation refers to the physical configuration of the interface, as well as to the presence of human facilitators. The design of the interface can impose limitations if it "facilitates, prohibits and hinders some actions, allowing, directing, and limiting behavior" [13]. In this case, the designer suggests a particular strategy or interaction trajectory using constraints. Interaction constraints could also be forced by human and virtual facilitators that pilot the interaction. Facilitators can show players how to interact with the interface and other players and how to accomplish tasks. If needed, the spatial environment should support the envisioned interaction. When designing collaborative installations, the physical set-up should encourage players to collaborate by constraining or facilitating their interaction, while a round space where players have the same distance from the object of the interaction would be appropriate for shared-control interfaces.

4. RELIABILITY OF THE FRAMEWORK

In order to argument the proposed framework, in this section we show how previous frameworks and taxonomies are accommodated within it. In Table 1 the main dimensions of the related work are associated with the elements proposed by MINUET.

Table 1. MINUET compared to related work (the first letter refers to the associated PACT entity).

Related work	Dimension	MINUET
Birnbaum 2005	Required expertise	P: Player
		A: Learning Curve
	Musical control	T: Control
	Feedback modalities	T: Feedback
	Degrees of freedom	T: Operational fr.
	Inter-actors	A: Collaboration
	Distribution in space	C: Physical env.
	Role of sound	A: Motivation
Wallis 2013	Incrementality	A: Learning Curve
	Complexity	
	Immediacy	
	Ownership	A: Ownership
	Operational Freedom	T: Operational Freedom
	Demonstrability	P: Audience
		P: Player
	Cooperation	A: Collaboration
Blaine 2000	Physical device	T: Input
	Player interaction	
	Learning curve	A: Learning curve
	Pathway to expertise	A: Ownership
	Physicality between players	A: Collaboration
		T: Embodied fac.
	Musical range	T: Control
	Media	T: Feedback
		A: Motivation
Overholt 2009	Gestures intuitiveness and perceptibility	P: Player
		T: Input
	Mapping richness	T: Mapping
	Range of expression	T: Control
Hunt 2000	Mapping strategies	T: Mapping
Cumhur Erkut 2011	Modality of interaction	T: Input
Johnston 2008	Modes of interaction	T: Input
Wanderley 20002	Learnability	A: Learning curve
	Explorability	T: Operational Fr.
	Feature controllability	T: Control
	Timing controllability	
Jordà 2004	Balance	A: Learning Curve
	Instrument efficiency	T: Control
		T: Operational Fr.
	Playability	A: Learning curve
	Learning curve	

5. HEXAGON, A CASE STUDY

We are now going to examine here a case study to demonstrate the prove the potential of MINUET for guiding designers throughout the design process of musical interfaces. To this end, we introduce the conceptual design of *Hexagon*, a tangible controller designed to train music cognition. Consistently with the declared purposed of the framework, we will focus on how to frame design challenges rather than detailing technical implementation.

5.1 Goal

Hexagon is designed to give players an interactive hands-on experience, which allows them to learn how to recognize the role of the most relevant musical parameters in Western compositions, such as mode, rhythm, harmony and tempo.

People. Hexagon targets amateurs and beginners (*Player*). The role of spectators is not relevant (*Audience)*.

Activities. Hexagon is designed to train their perception of musical composition, i.e. to become aware of musical form and progression (*Motivation*). Following a social-constructivist approach to learning, cooperation among players is expected (*Collaboration*). Given the educational purposes, the initial complexity needs to be kept under control; a sufficient longevity, though, must be ensured in order to keep players engaged (*Learning curve*).

Contexts. As music language we use tonal music, as it is broadly known and complex enough to include the most important parameters of Western music (*Music style*). The interface can be experienced individually or collectively, at home or at school (*Social environment*). Spatial elements are not crucial (*Physical environment*).

5.2 Specifications

Once our goals have been outlined, this stage focuses on prototyping possible design implementations. We want players to learn the influence of a number of musical parameters by means of physical interaction. This implies that they will interact with tangible objects, each of which is associated with a specific parameter. The music is generated by Robin, an algorithm that automatically composes an original tonal music [21]. Players can create music operating on compositional and performance parameters. Compositional elements are usually marked by the composer in the score, while performance behaviors are left to performers' interpretation during the execution. Hexagon simulated the same distinction: players can interact using one of two input modalities.

5.2.1 Compositional Parameters.

Six squared flat boxes are associated with six compositional parameters (i.e. mode, harmony, harmonic intervals, melodic direction, melodic range, and melodic motion). Positioning the boxes on the sides of a central *hexagon*, players define the desired values for each parameter (Figure 2). These values feed the algorithmic composer, which generates the music accordingly. While not directly operating on low-level parameters, the interaction metaphor remains in the musical domain (divergent *Mapping*). An example of interaction is shown in Figure 2: the music is set in major mode, consonant harmony and consonant harmonic interval, and the player is attaching the block describing the melodic direction.

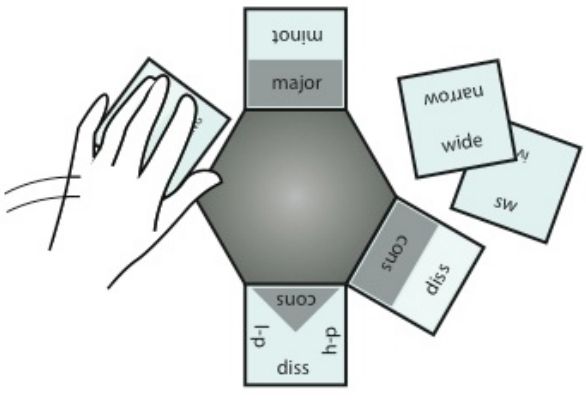

Figure 2. Placing the boxes around the hexagon allows controlling compositional parameters.

5.2.2 Performance behaviors

While the music is playing, the user can subtly intervene on performance behaviors interacting with a multi-touch hexagon (*Control,* Figure 3). Here players have direct access to sonic features (direct *Mapping*). They can influence the timing, volume and attack tapping on the hexagonal pad. Furthermore, they can perform a number of behaviors such as vibrato (through a gentle and fast movement of the fingers) and legato (through a gesture which is reminiscent of the *hammer-on technique performed by guitarists*). Figure 3 features the example of a player who is tapping tempo with his right hand while performing a vibrato with the left.

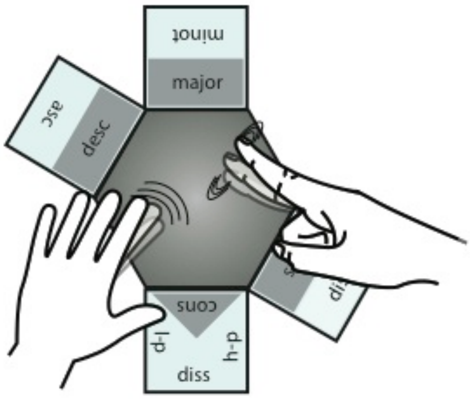

Figure 3. Interacting with the central hexagon influences performance behaviors.

When interacting with performance elements, players have direct access to the low-level control and therefore experience more *Operational Freedom* then they do when interacting with compositional ones. However, this privilege is counterbalanced by the time required for mastering them (*Learning curve*). We argue that dividing the musical creation process into two phases will help the player to understand the distinction between the two sets of parameters (*Embodied facilitation*).

6. CONCLUSIONS AND FUTURE WORK

A general consensus suggests that a technology-oriented design well suits musical controllers that resemble the physicality and the objectives of acoustic instruments [19]. If we considered musical interfaces as an umbrella term that also includes interactive installations [4, 31], however, this approach may prove inconsistent, due to the diversity and the complexity of this design space. Designers working on this category of interfaces, indeed, tend to focus on a particular user experience rather than a precise set of musical activities. Performing formal design and evaluation strategy might turn out to be very demanding.

Through a systematic review and a reinterpretation of related design dimensions and heuristics, this study proposes a new conceptual model that aims at tackling this issue. The fruit of this research, MINUET, is meant to stimulate reflection on both an abstract and a practical level when designing novel musical interfaces. As well as incorporating all the varieties of musical interfaces (addressing this design space and leaving behind the somewhat artificial boundaries intrinsic to any definition), MINUET offers two important contributions. First, it shifts the focus of previous frameworks framing a design space of musical interfaces centered on players' experience. Second, to the best of our knowledge, this is the first attempt to develop a framework with a precise temporal unfolding rather than a set of heuristics.

This study laid the foundations for developing a framework for the design and evaluation of musical interfaces. So far, we provided a conceptual model that frames designer's goals into a set of specifications. The next step will be to investigate how these specifications can be validated through a series of success criteria. Afterwards, we will conduct a study to examine how to gather empirical data on the basis of success criteria in their natural setting. Due to the hedonic nature of the interfaces and due to the fact that they are often used in non-controlled live conditions, most of the traditional HCI techniques for evaluating users experiences cannot indeed be applied to this design space.

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