A Methodological Framework for Teaching, Evaluating and Informing NIME Design with a Focus on Expressiveness and Mapping

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ABSTRACT

The maturation process of the NIME field has brought a growing interest in teaching the design and implementation of *Digital Music Instruments* (DMIs) as well as in finding objective evaluation methods to assess the suitability of these outcomes. In this paper we propose a methodology for teaching NIME design and a set of tools meant to inform the design process. This approach has been applied in a master course focused on the exploration of expressiveness and on the role of the *mapping* component in the NIME creation chain, through hands-on and self-reflective approach based on a restrictive setup consisting of smart-phones and the Pd programming language.

Working Groups were formed, and a 2-step DMI design process was applied, including 2 performance stages. The evaluation tools assessed both System and Performance aspects of each project, according to Listeners' impressions after each performance. Listeners' previous music knowledge was also considered. Through this methodology, students with different backgrounds were able to effectively engage in the NIME design processes, developing working DMI prototypes according to the demanded requirements; the assessment tools proved to be consistent for evaluating NIMEs systems and performances, and the fact of informing the design processes with the outcome of the evaluation, showed a traceable progress in the students' outcomes.

Keywords

NIME, teaching, evaluation, design, methods, framework, mapping, expressiveness

1. INTRODUCTION

Since the birth of NIME in 2001 as an academic and practitioner conference that initially attempted to answer the question of *how to better play musical computers* by exploring connections with the better-established field of human-computer interaction (HCI), the NIME field has matured, integrating knowledge and practices from different disciplines. In parallel to this maturation process, there has been a naturally growing interest in teaching the design and implementation of *Digital Music Instruments*(DMI) as well as in finding objective - or at least useful - ways of evaluating the quality or the suitability of these outcomes.

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In this paper we propose a methodology for teaching NIME design and a set of evaluation tools meant to inform the design process. These methods have been applied in a one-trimester NIME master course that has focused on the exploration of *expressiveness* and on the crucial importance of the *mapping* component in the NIME creation chain, by using a quite restrictive setup consisting only of smart-phones controllers and the Pd programming language [22]. To make the students fully aware of the relevance and, at the same time, the intrinsic difficulty of NIME evaluation, we have conceived a complete hands-on and self-reflective approach, in which the students were asked (i) to a design a DMI (with the aforementioned important and predefined constraints), (ii) to perform with the instrument in front of the rest of the class, and (iii) to evaluate these performances as listeners, in an iterative process.

This paper is structured as follows. We first present an overview of the existing NIME strategies in the context of education, design and evaluation. We then introduce the course, describing its context and its peculiarities. We describe the evaluation methods developed for assessing the projects created by the students, we detail how we applied this evaluation to inform iterative design, and we analyze and discuss the obtained results. We conclude discussing relevant findings and challenges, and how these could inform other NIME practitioners, educators or designers.

2. TEACHING, DESIGNING AND EVALUATING NIME

In 1999, two years before the first NIME conference, Michel Waisvisz, artistic director of the Dutch center for research and development of new musical instruments STEIM from 1981 until his death in 2008, and one of the few undeniable NIME virtuosi, complained about the apparent lack of progress and the permanent reinvention of the wheel that seemed to be going on in the realm of musical gestural controllers: "A growing number of researchers/composers/performers work with gestural controllers but to my astonishment I hardly see a consistent development of systematic thought on the interpretation of gesture into music, and the notion of musical feed-back into gesture." [28],[29].

2.1 Teaching NIME

Fifteen years later, the design of DMIs no longer relies solely on the Promethean efforts of some romantic and isolated pioneers. While a course on controllers taught at Stanford's CCRMA was already presented in the first NIME Workshop in 2001 [27], in the last years numerous NIME courses have sprung up at universities around the world. A special workshop devoted to NIME education took place at NIME 2011, with the aim of providing a structured forum for NIME educators to share their approaches, experiences and perspectives on teaching NIME curricula [12]. Identifying the main differences and peculiarities between currently existing NIME courses would completely fall out of the scope of this paper. Instead we summarize the common features they typically share.

Courses tend to be taught at the beginning of graduate or senior undergraduate levels [18]; they tend to be very multidisciplinary, often bridging the gap between art and science education [17], and thus agglutinating students from very different backgrounds and different levels of knowledge (e.g. fine arts, music, computer science, engineering, interaction or product design, etc.). While some courses are more closely defined and more knowledge oriented than others (i.e. the competences to be acquired during the course may include a given set of tools, technologies or procedures), they mostly tend to be project oriented and students learn what they need in order to develop their own projects, which are then finally presented in live performance or demo scenarios [18].

While very often these projects give great freedom to the students - typically only limited by the technical resources and the know-how available at each center - the lack of a shared technological knowledge among these students, makes technological topics prevalent (e.g. how to use different sensors; how to connect them to a micro-controller; how to synthesize/process sound in a programming environment such as Pd, Max/MSP, SuperCollider or Chuck, etc.) and more important than design aspects or more conceptual criteria.

Finally, most courses tend to instruct on how to create new DMIs, most often eluding the question of how to improve them or make *better* ones, whatever this adjective may mean. This leads us to the next section, in which we present an overview on the existing frameworks for the design and the evaluation of DMIs.

2.2 DMI Design and Evaluation Frameworks

Is Waisvisz's initial quote still valid? Are the designers of DMIs (who may also be performers, composers and/or researchers) still blindly working in a field which shows no consistent development of systematic thought? Inseparable from concepts so complex and elusive as *music* or *taste*, the NIME realm may indeed always remain an area impossible to reduce and systematize, or as Perry Cook put it in the first NIME workshop in 2001, "Musical interface construction proceeds as more art than science, and possibly this is the only way it can be done." [6]. Creating DMIs is indeed in many respects, very similar to creating music. It involves a great deal of different know-how and many technical issues, while at the same time, like in music, there are no inviolable laws. But even if we may agree in the fact that the NIME discipline will never become a science, this should not prohibit us from thinking about it and analyzing its outcomes, and in particular, it should not prevent us building on the successes and the failures of experienced practitioners. Not unlike much research in HCI culminates in lists of guidelines and/or principles for design (and/or evaluation of design) based on research or practical experience relating to how people learn and work, it comes as no surprise that the first tentative *NIME design frameworks* have been mostly proposed by experienced *digital luthiers* [14].

In the same aforementioned paper in which he debates about NIME, art and science [6], Cook delivers his first *principles for designing computer music controllers*. As pointed out recently by O´Modhrain [20], Cook's paper (and most of the following frameworks as well), which includes statements such as "copying an instrument is dumb, leveraging expert technique is smart", sets the goals for desirable properties of successful DMIs, yet saying little about how to achieve these goals. Jordà proposes a conceptual framework that could serve in evaluating the potential, the possibilities and the diversity of new digital musical instruments, focusing on the expressive possibilities these instruments can offer to their performers. It discusses in depth several DMIs desirable properties or goals such as the instrument's playability, learnability, musical efficiency, variability, reproducibility, explorability or diversity (the ability of an instrument to support diversity in musical style and performance), and how each of these different properties can promote/support different performance needs and approaches, such as the ones desirable in a instrument for novices, or the ones required for developing virtuosity [14]. Studying *expression* in digital musical performance, Dobrian and Koppelman also stress the importance of virtuosic mastery, and how this can be promoted with intuitive but complex gesture-sound mappings (together with obvious long-term dedicated practice)[7]. All the aforementioned authors elude however the delicate issues of how to clearly attain these design goals and how to objectively evaluate them.

The task of evaluating DMIs is in fact strongly linked to that of designing them, and knowledge gained in any side of the equation should complement the other. It is also clear that the traditional evaluation methodologies coming from HCI tend to be unsuited to the even more subjective evaluation of DMIs [4]. And yet, directly inspired by HCI, Wanderley and Orio [30], provide one of the first sets of guidelines to aid in selecting suitable tasks for evaluating DMI designs. Although these guidelines and tasks do not constitute in themselves methods for evaluation, they definitely bring observations that can constitute good evaluation starting points.

More recently O´Modhrain [20] presents an excellent and detailed overview of previously existing DMI evaluation frameworks that we urge the reader to consult, and proposes the evaluation of DMIs from the diverse and complementary perspectives of all the stakeholders involved in the process. This list includes performers, audiences, composers, instrument builders, component manufacturers and customers, and assumes that each of these stakeholders may have different ideas of what *evaluation* may mean, and that DMI designs should be therefore evaluated from these multiple perspectives. O´Modhrain's paper follows by providing a list of goals such as *enjoyment*, *playability*, *robustness* or *achievement of design specifications*, that should be therefore confronted from the diverse perspectives of each stakeholder. Following these suggestions, Barbosa et al. [3] deepen in evaluation methodologies from the perspective of the audience, while Gurevich and Fyan focus on the relationship between performers and digital systems and on the spectatorsâĂŹ perception of these interactions [11]. Among other recent publications, Gelineck and Serafin [9], insist in the importance of longitudinal studies carried along longer periods of time, in an atttempt to study the development of virtuosity. Along similar lines, Marquez-Borbon et al. [19] study the evolution of skill development interviewing and following a group of users for several months, while they also propose the conception and design of *experimental DMIs* for specific evaluation purposes (as opposed to artistic purposes). Kiefer [16] also uses his own DMIs for proposing the combination of HCI inspired methodologies and grounded theory methods for assisting the design, use and evaluation of creativity support tools with a focus on multi-parametric DMIs. In essence, while the search for solid and grounded design and evaluation frameworks is one of the main trends in current NIME research, general and

Table 1: Structure and Contents of the Course

Session	Content	Readings next session	Assigment next session
0		[23],[25]	
1	Introduction and discussion on 'interaction' and the 'evaluation of interactivity'	Start reading the Pd tutorial [1]	Think about potential real-time applications
2	Real-time interaction (technical, perceptual and design issues)	Selected and abridged info on sound and digital audio (Hz, pitch, dB...)	Build basic Theremin with sine oscillator in Pd. Control pitch, amplitude and add a 'nice' and natural vibrato control
3	Pd hands-on exercices	Interactive music: [5]	Build monophonic synth with 2-3 continuous parameters. Don't worry about the interface: just put sliders
4	Interactive music overview (historical, conceptual)		Find videos of 'expressive' performances (acoustic, electric, electronic...) with a focus on timbre control
5	Expressiveness. Timbre navigation videos: Tuvan singing, didgeridoo, wah-wah brass, electric guitar	Selected and abridged info on audio filters, subtractive and modular synthesis	Add filter and LFO to your synth. Download OSC app for your smartphone/tablet (IOS/Android)
6	MIDI, OSC, sensors and accelerometers. Connecting smartphones/tablets to Pd		Create minimalistic smartphone interface for your synth. No sliders; just continuous control from accelerometers, compass, 2D multi-touch... Focus on timbre; forget pitch. Get ready for the 1st performance
7	1st performance and on-line evaluation questionnaire	Control: [24],[21]. Mapping: [13],[2]	Check the feedback from your colleagues and continue enhancing your synth
8	Mapping and non-linearity	[14](chap.7)	Continue enhancing your synth
9	Pd hands-on: feedback, distortion, non-linear many-to-many mappings	[26]	Focus on non-linearity and many-to-many mappings. Get ready for the 2nd performance
10	2nd performance and on-line evaluation questionnaire	[8],[10]	Document and upload your final synth
11	Machine learning in HCI	[20]	
12	Evaluation methods in HCI and NIME. Final discussion		

formal methods that go beyond specific use cases have probably not yet emerged. Will these be the *El Dorado* or the *Holy Grail* of NIME research?

3. CASE STUDY: A COURSE ON REAL TIME INTERACTION

3.1 Context of the Course

We now propose a methodology for teaching NIME design and a set of evaluating tools intended to inform the design process. These methods were recently developed for - and applied in - a one-trimester graduate course called *Real-time Interaction*, compulsory for students of two separated and quite diverse one-year master programs, one in *Sound and Music Computing* and another in *Cognitive Systems and Interactive Media*. The background and interests of both types of students tend to be quite different. *Sound and music* students have clear musical interests, most often playing one or several musical instruments, and tend to come also from more technical engineering backgrounds, thus often having prior experience in some type of computer programming. *Cognitive Systems* students, on the other hand, come from more diverse backgrounds (psychology, sociology, humanities, design, mathematics, architecture, etc.) and most often do not have any prior experience in music performance nor in computer programming. Finding a suitable balance that would satisfy both sides has never been an easy task. For this pragmatic reason, previous deliveries of the course did not explicitly focus on NIME design, but rather in analyzing the characteristics and differences of *real-time interaction* in different contexts (e.g. NIME, video games, augmented reality, etc.) from a more conceptual point of view. In 2013 we decided to face the challenge. Would it be possible to conceive a more hands-on course that (i) from a technological perspective, would be challenging and yet feasible for all types of students (musicians vs. non-musicians, programmers vs. non-programmers), and that (ii) from a conceptual and theoretical perspective would also provide enough food for thought and useful learning for all participants?

Taking into consideration some of the properties that constitute the intrinsic and more relevant features of *real-time interaction* when compared to more conventional WIMP interaction, namely the multidimensionality, multi-modality and the continuity of the input space [15] we decided to focus on the systematic exploration of two *advanced* NIME topics, assuming that the conceptual challenges they would provide would not be substantially minor for the *Music students* than for the *Cognitive Systems students*. Also the later could benefit from some of the learnings, being able to subsequently extrapolate them to their particular research areas. The two chosen topics for exploration were *expressiveness* and the crucial importance of the *mapping* component in the NIME creation chain.

Introducing a formal evaluation process into the course seemed also essential for us for two complementary reasons. From the educators' perspective, there was a clear pedagogical objective in making the students fully aware of the intrinsic difficulties of evaluating complex and *creative* interaction contexts. On the other side, as researchers, we were carrying out our own parallel experiments (or even perhaps *meta-experiments*). These should be able to inform us about at least three main topics. Firstly, following O´Modhrain's ideas on stakeholders [20] we wanted to experiment with evaluation methods in which participants would swap between different roles (i.e. *Designers*, *Performers* and *Listeners*) and analyze how previous music knowledge would affect each of these roles. Secondly, we wanted to investigate to what extent the proposed evaluation method could inform iterative design processes. Lastly, we also expected to shed some additional light on the elusive concept of *expressiveness*.

From a technical point of view, and unlike most NIME courses that tend to offer a free or at least wide enough approach to technology, we decided to restrict ourselves to two technological tools, namely using smart-phones as controllers and the Pd programming language [22] for audio synthesis and processing. This decision was also taken for two main reasons: to eliminate all accessory technical information that would probably only add confusion to the least tech-savvy students, and to carry on our experiments in a reasonably constrained and controlled scenario.

3.2 Structure and Contents of the Course

Real Time Interaction takes place in the first trimester (October-December) of the academic year and is composed of 12 weekly 2-hour classes. This year 35 students took the course, with approximately half coming from each of the two above mentioned master programs. Most *Sound and Music Computing* students had some musical knowledge, playing one or several instruments and being familiar with Digital Audio Workstations and electronic music production. This information was obtained through a questionnarie as described in section 4. Most also had some computer programming knowledge and several were even familiar with Pd or Max/MSP, although none had worked on real-time electronic music performance. With some exceptions, most of the *Cognitive Systems* students on their side, did not have any prior musical experience. Although some were engineers acquainted with computer programming, none of them had ever worked with digital audio or dataflow programming languages. Special efforts were needed in order to find a right balance between novelty and viability that would satisfy almost everyone, a goal that was almost achieved. No student found the course too trivial and only two complained about its difficulty. Table 1 shows the topics covered in the course, along with the recommended readings and the assignments required for each of the 12 sessions.

The topics covered, which did progressively deepen from the more general to the more specific, can be synthesized as follow: starting with the concept of interaction and the problems deriving from the evaluation of interactivity (session #1), the special characteristics of real-time interaction were highlighted (#2), then the particular case of musical interaction with DMI was studied (#4), for subsequently focusing on timbre control and navigation (as opposed to more traditional pitch-based control), trying to elucidate the meanings of expressiveness (#5), and investigating how more complex (especially non-linear - many-to-many) mappings [13] [26] could affect achieving this objective (#6). To encourage participation and discussion, students were asked to read several papers before each new topic was introduced, the full list of which can be also consulted in Table 1.

Additionally, all these concepts were experienced hands-on by the students with progressively sophisticated implementations using Pd. These started from a simple Theremin with vibrato control (#2-3) and went into several iterations of a monophonic synthesizer with increasing timbral control parameters (#3-4, #5-6), that later was controlled from a smartphone/tablet using the OSC protocol [31] with increasingly complex mappings (#6-7, #7-8, #8-9). While during the first sessions students worked individually, after session 3 they created 11 Working Groups (of 2-4 students) that remained stable for the rest of the course. Sessions 7 and 10 constituted the backbone of the evaluation method, since in these two sessions each Working Group performed a 2 to 3 minutes piece/improvisation that was evaluated by all the other students, as described in detail in the next section. Performances were video-recorded and made available to the students for a more detailed evaluation.

After the 2nd performance (#10), session 11 was devoted to the use of machine learning techniques for NIME control mappings [8],[10]. Although one of the initial objectives when envisaging this course was to include a 3rd performance/iteration using these techniques, it turned out clear from the beginning that it would be impossible to grab as much content in a 12 weeks course, so this topic remained at the theoretical level and was presented to the students as a potential follow-up to their work. Finally, session 12 provided an overview of *evaluation methods and issues in HCI in general and NIME in particular*, which concluded with a discussion of the results of the evaluation.

4. EVALUATION METHOD

The methods applied during the master course were designed to assess both the *System* and the *Performance* aspects of the developed projects. Through this approach, we were able to evaluate the proposed DMIs in different stages, and explore how this evaluation can inform iterative design. Learning aspects, however, were not assessed.

Twenty two students (7 females), mean age 25.3 (SD = 2.15) participated in the evaluation. 13 students were dismissed, as they did not follow the procedure accordingly (i.e. missing responses in the questionnaire). Participants' demographic data (age and gender) and previous music knowledge (capability for playing music and electronic music) were measured at the beginning of the master course through a questionnaire.

During each performance session, all participants (in the *Listeners* role), completed a 5-point Likert scale questionnaire to assess both *the System* (the DMI itself) and *the Performance* (related to the use of the DMI and the quality of the musical output). The *System's* properties were measured according to 3 variables:

Mapping richness. Statement: "I have found the control mapping rich and interesting".

Synthesis richness. Statement: "I have found the sound synthesis rich and interesting".

Potential. Statement: "The system shows great potential as a DMI".

Performance's aspects, on the other hand, were assessed through the following variables:

Musicality. Statement: "I have found the performance musical".

Expressiveness. Statement: "I have found the performance expressive".

Virtuosity. Statement: "The performers were able to control de instrument as real virtuosi".

These variables, whose choise was influenced by [14] and [20], had been previously debated in class to assure a consistent interpretation during the evaluation process. Each Listener fulfilled the questionnaire after each performance (except their own). Together with the questionnaire, tags and comments about the projects were also collected.

5. RESULTS

For analysis purposes, the sample was divided in two groups: High Music Knowledge (HMK, 15 participants) and Low Music Knowledge (LMK, 7 participants), and in two stages (1st and 2nd Performances). A Pearson Correlation analysis was applied to test the coherence and strength of the two Categories of variables (System and Performance properties). An analysis of Variance (ANOVA) was applied to find significant differences between 1st and 2nd Performances. For this analysis, Bonferroni correction of significances was applied for multiple comparison, and alpha was fixed at 0.05 for all statistical tests.

5.1 Correlation Analysis

The correlation analysis showed significances for both 1st and 2nd Performance stages. More specifically, *Musicality*, *Mapping Richness* and *Synthetic Richness* were positively correlated for in both 1st and 2nd Performances. On the other hand, (*Potentiality*, *Expressiveness*, and *Virtuosity*) also showed a significance correlation for both stages. Table 2 shows the direction and strength of significant correlations in both stages.

5.2 Between Stages Analysis

When analyzing differences between 1st and 2nd Performances without considering previous music knowledge (all *Listeners* together) three variables (*Potentiality*, *Expressiveness* and *Virtuosity*) reached significance for 3 of the 11 projects (see Table 3). When analyzing between-stages differences according to previous music knowledge, a different picture emerges. For the HMK group, only two variables (Expressiveness and Virtuosity) reached significance for two projects (see Table 3). The LMK, on the other hand, did not show any significance.

Table 2: Pearson Correlations for Performance and System. Only significances are shown (* p < 0.01)

Variable	Mapping	Synthesis	Potential	Musicality	Expressiveness	Virtuosity
Mapping		$r = .450*$		$r = .334*$		
Synthesis	$r = .450*$			$r = .502*$		
Potential					$r = .505*$	$r = .391*$
Musicality	$r = .334*$	$r = .502*$				
Expressiveness			$r = .505*$			$r = .591*$
Virtuosity			$r = .391*$		$r = .591*$	

Table 3: Analysis of Variance between 1st and 2nd Performances for the whole sample (All), and High and Low Music Knowledge (HMK/LMK). Only significant differences are shown. Alpha for Bonferroni-corrected significances set at $p < 0.05(*)$

DMI	All	HMK	LMK
4	Expressiveness ($F(9.20) = 1.43)*$		
5	Potential ($F(5.90) = 1.44)*$ Expressiveness ($F(6.30) = 1.6)*$	Expressiveness ($F(9.20) = 1.62)*$	
11	Expressiveness ($F(9.20) = 1.51)*$ Virtuoso ($F(4.60) = 2.10)*$	Virtuoso ($F(7.18) = 2.1)*$	

6. DISCUSSION

6.1 Analysis of the Results

The statistical analysis showed that the proposed Categories of analysis (Performance and System) were coherent and consistent independently of Listeners' previous music knowledge. In spite of these findings, two variables (*Musicality* and *Potential*) showed to be correlated with the opposite Category, namely System for *Musicality* and Performance for *Potential*. This can be explained by a certain level of ambiguity in the operationalization of these variables in the questionnaire (i.e. the way in which the questions were formulated). This has occurred despite the musical background of Listeners. The outcome of the statistical analysis, however, helped us to rearrange the variables according to their coherence.

The ANOVA, on the other hand, showed that the methods presented are sensitive to participants' music knowledge. In this regard, certain music knowledge would be desirable in order to properly understand the questionnaire. We also have to mention that the disparities between groups (LMK was half of the size of the HMK group) does not allow us to fully describe the impact of musical knowledge in understanding the questionnaire. In sum, in order for future studies to built on top of this method and evaluate similar educational settings, group sizes and music knowledge should be normalized. Moreover, the addition of qualitative tools such as interviews and open questionnaires could complement statistical validity. This could bring a better understanding of how the proposed method can contribute to improve the DMI design process, beyond the natural enhancement resulting from mere iteration.

6.2 Analysis of the Initial Objectives

As stated in the Section 3, the main objectives of this course/ study covered both pedagogical and research issues. From a pedagogical perspective, the focus was on the role of *Expressiveness* and *Mapping* in the DMI design process, and on the value of our evaluation tools to feedback meaningful information to the iterative design process.

In this regard, the Case Study has shown that the students got actively engaged in a DMI design process, with the evaluation informing the development and improvement of prototypes. Although only 3 out of 11 projects reached significant differences when comparing the 2 design stages, almost all DMIs showed improvements after iteration. A bigger and equilibrated sample will undeniable reflect the contributions of these evaluation tools in the design process.

It is also worthy to discuss to what extent the design guidelines imposed during the course either constrained or helped students to focus on core aspects of the DMI design chain. In this sense, the fact that all groups achieved operative DMIs shows that the proposed guidelines helped to leverage the students' background, fostering collaboration between students with different skills.

Our research goals, on the other hand, aimed at studying how these methodologies can cover different stakeholders. Although we present methodologies mainly focused on *Listeners* and their music knowledge (meaning that although all participants exerted the 3 roles, they only evaluated from what they heard from their colleagues performers, without testing the other DMIs themselves) the results show the relevance of Listeners' perception for informing iterative design of DMIs. Future studies could broaden the scope of this paper by also considering Designers and Performers. Analysis in such direction were limited in this Case Study, as Working Groups were mixed concerning music knowledge, and the Designer/Performer roles remained together during the whole process.

Finally, the internal analysis of each project was not covered by this study. Since we did not analyze the relation between the implementations and the feedback received, no conclusion can be taken yet on the interactions between mapping and expressiveness. Data was collected in this regard, in the form of smartphones GUIs, Pd patches (which incorporated all the mappings), video recordings and written reports, so future work can be devoted to such analysis.

6.3 Future Work and Contributions

A number of guidelines for future work can be envisioned in response to the faced challenges and problems. Firstly, the proposed evaluation tools have to be tested in different NIME design scenarios. Regarding the grouping of participants by music knowledge, experimental groups should be leveraged for achieving better statistical validation, and for analyzing in depth the effect of musical background in the design, performance and evaluation process. In the same direction, the roles of Designer and Performer should be detached and analyzed separately, together with the influence of music knowledge for both stakeholders. In this regard, we envision an experiment where performers could select their favorite DMIs designed by other Working Groups and perform with them for later evaluation. Concerning the design guidelines, the proposed methods should be tested with other design constraints, and future work should also deal with the analysis of the DMIs themselves, to go beyond *Listeners'* perception of systems and performances. Finally, we aim at complementing this quantitative assessment with qualitative methods such as interviews and focus groups, in order to better suit practice based educational research.

7. CONCLUSION

In this paper we have presented a methodology for teaching NIME design, together with a set of evaluation tools meant to inform the design process. These methods have been applied in a Case Study focused on the exploration of "expressiveness" and "mapping" as crucial components in the

NIME creation chain, and making use of a quite restrictive setup consisting only of smart-phones controllers and the Pd programming language. Working Groups were formed, and a 2-step DMI design process was applied, including 2 performance stages. The evaluation tools assess both System and Performance aspects of each projects, according to Listeners' impressions during each performance stage. Listeners' previous music knowledge was also considered.

The learning and knowledge that we have gained through this iterative methodology is threefold: (i) all the students (some of whom had never performed music, neither programmed computers) were able to effectively engage in the NIME design processes, being able to develop working NIME prototypes that fulfilled all the asked requirements; (ii) the assessment tools proved to be a consistent method for the evaluation of NIMEs systems and performances; (iii) the fact of informing the design processes with the outcome of the evaluation, showed a traceable progress in the students' outcomes. Although these findings were obtained in the specific context of a NIME course, we believe that several of these solutions and learnings could be extrapolated to more generic contexts, being other NIME or even HCI courses, design methodologies and evaluation methods for both fields, and could therefore inform teachers, designers and practitioners in general.

8. ACKNOWLEDGMENTS

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