Design for Longevity: Ongoing Use of Instruments from NIME 2010-14

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ABSTRACT

Every new edition of NIME brings dozens of new DMIs and the feeling that only a few of them will eventually break through. Previous work tried to address this issue with a deductive approach by formulating design frameworks; we addressed this issue with a inductive approach by elaborating on successes and failures of previous DMIs. We contacted 97 DMI makers that presented a new instrument at five successive editions of NIME (2010-2014); 70 answered. They were asked to indicate the original motivation for designing the DMI and to present information about its uptake. Results confirmed that most of the instruments have difficulties establishing themselves. Also, they were asked to reflect on the specific factors that facilitated and those that hindered instrument longevity. By grounding these reflections on existing reserach on NIME and HCI, we propose a series of design considerations for future DMIs.

Author Keywords

Design, evaluation, performance, survey, digital musical instrument, user experience

ACM Classification

[Applied computing] Sound and music computing, [Human-centered computing] HCI theory—Concepts and Models

1. INTRODUCTION

In 2004 Jordà memorably remarked that "many new instruments are being invented. Too little striking music is being made with them" [10]. Since then, an even more copious number of instruments have been created, facilitated by increasing interest in DMI research in academia and by the crowdfunding revolution that has made production widely accessible.[1]

Despite this, most DMIs still seem to have difficulties establishing themselves after their creation. Mamedes and colleagues urged a self-criticism within the NIME community: *"A huge number of DMIs are presented every year and few of them actually remain in use"* [12]. Some musicians have mastered new instruments through extended use (e.g. Leatitia Sonami's Lady Glove and Michel Waisvisz's The Hands), but it is common for new DMIs to be set aside after only a few performances.

Acknowledging this limitation, throughout the years, several design frameworks have been proposed to offer musical instrument designers a theoretical base by proposing design heuristics [18, 20] and suggesting evaluation methods [8, 30]. In most of the cases, these frameworks were generated with a top-down approach, which might lack empirical observations on the precise factors that facilitate or hinder the establishment of an instrument.

Several of these factors lie outside the interest of our community (e.g. production models, advertisement, sponsorship), but others are directly connected with our daily exercise. In particular, which specific design practices should DMI makers follow to facilitate a prolonged use of the instrument? What are the most common design "mistakes" that we make, which should better off brought to the fore?

This paper aims to provide a pragmatic answer to these issues in an inductive way by directly questioning the design practices of NIME members. We isolated the 97 papers presented at five successive editions of NIME - from 2010 to 2014 - that introduced a new DMI[2] (Section 2). We then sent the main authors an online survey, which asked them to indicate the original motivations and the ongoing use of their DMI, and to reflect on the causes of its success or lack of success. We received 70 answers, which we analysed quantitatively and qualitatively.

With respect to the ongoing use of the DMIs, the answers from the authors (Section 3) confirmed that the percentage of DMIs that "broke through" (e.g. that have ongoing projects, are regularly performed in public, and received commercial interest) is quite low.

In terms of design practices, we identified a number of factors that facilitate or hinder the uptake of an instrument (Section 4) by integrating considerations from the authors with typical HCI theory and practice. If some of the findings do not come as a surprise (e.g. a simple interaction is advantageous), others offer considerations that merit further attention in our community. For instance, instrument design should include "signature features" that are exclusive to that DMI and support unique playing styles.

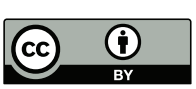
2. METHODOLOGY

2.1 Paper selection

We selected papers presented at five successive editions of NIME, from 2010 to 2014. We did not include papers from

[1] In 2015 and 2016 only, 28 new musical instruments have been proposed on Kickstarter; 18 were funded. Source: `http://www.kickstarter.org`

[2] With DMI we refer to all the *new interfaces for musical expression*, not just the digital ones. We acknowledge that some of the presented interfaces are not digital at all, but we chose this acronym to disambiguate with that of the conference.



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the last two editions because of the infancy of the work: rather than focusing on the spike of usage of a newly created interface we were interested in legacy, which requires maturity of a project.

We acknowledge that this selection fails to account for the multiplicity of instruments and DMIs that were not presented at this conference - in particular, commercial DMIs and those presented at the yearly Guthman musical instrument competition[3]. However, the scientific rigour obliged us to have a clear selection method, a demarcation line that would be difficult to trace with commercial DMIs. Further, DMIs that were not presented at academic conferences lack formal documentation that is needed to track their development and draw formal comparisons among them. For this reason, we also omitted the DMIs that were only presented at the performance track of NIME, as they are not included in conference proceedings. The works presented at other related conferences and journals falls out of the scope of this paper but would make interesting future research.

Following the objective of this paper of determining what design factors facilitate a long-term engagement with an instrument we restricted the investigation to the DMIs specifically intended for solo human performer (as opposed to a machine intelligence) to be able to play live in a concert-like setting and that could potentially lead to prolonged use by musicians and develop virtuosity.

We included: augmented instruments, software instruments, controllers, mobile and tablet applications, systems for performance, and sequencers. Everything else was excluded: audience-controlled instruments and installations, algorithmic accompaniments, live coding and laptop orchestra, design probes, and instruments that target specific age or medical conditions. In a few cases, the demarcation line was not clear. In these cases, we adopted a relaxed policy and included the paper (e.g. we included three robotic instruments conceived to be partially played by a human performer). Using these criteria, 97 papers made the cut.

2.2 Questionnaire

An online questionnaire was prepared to provide answers to our research questions[4]. It included 27 entries that asked about different aspects that are relevant to the issues addressed in this paper. The questionnaires were sent via email to the first author of each paper. A total of 70 answers were collected (72% response rate).

We acknowledge that the figures describing the DMIs uptake reported in Section 3 fail to account for the 27 authors that did not reply to our survey. However, the present investigation is mostly intended to measure the general temperature of the DMIs presented at NIME rather than offering meticulous statistics about their adoption. That being said, the design consideration described in Section 4 would have greatly benefited from comments of the creators of the DMIs that became popular even outside the academic community (e.g. the Roli Seaboard[5], the Magic Fiddle[6], and the AlphaSphere[7]), and the discontinued ones alike.

2.3 Data analysis

The uptake of the DMIs (Section 3) was assessed by analysing and comparing information about the author's original motivations, their target users, the current state of the DMI, the number of public performances in which the DMI was used, the number of artists that performed with the DMI and projects in which it was used, and sale information when available.

To extract design considerations (Section 4) we integrated creators' reflections about the reasons for the longevity of their instrument and aspects they would have done differently with quantitative answers to some survey questions.

A thematic analysis with an inductive approach [3] was performed on this data. Endorsing the idea that idiosyncratic experiences with the design of a single DMI could provide other makers with a crucial example, both as a suggestion to follow enduring design decisions or to avoid repeating pitfalls, codes were associated to comments received from a single author and to shared opinions.

The last step consisted in clustering codes into practical design considerations. To this end, we examined the codes taking into consideration design factors typical of NIME [10, 18, 29] and of the broader HCI community [4, 24].

Table 1: For whom did you make it?

Target user	Freq.
"For myself"	58
"For the broader public, including non-musicians"	29
"For musicians generally"	20
"Other"	18
"For a specific category of musicians"	9
"For a specific musician other than myself"	9

Table 2: Motivations to develop the DMI with Frequency and Loadings, divided by Component

C	Motivation	F	L
1	"To publish at NIME"	17	.704
	"To test a new technology"	27	.691
	"As a reserach probe"	38	.687
2	"Nothing available to do what I wanted"	41	.755
	"To write a piece for it"	18	.726
3	"To complement my artistic practice"	34	.627
	"As an assignement for school"	18	-.716

3. INSTRUMENT UPTAKE

We retrospectively documented whether the original intentions for building the instrument were met and we serached for possible patterns of instrument uptake. This section reports the results of this investigation.

3.1 Target user and original motivation

To start with, we asked the authors to indicate for whom they made their DMI. Authors could choose as many answers as they wish. The results indicate that the most common target user was the author themselves (Table 1).

Next, we asked the reasons that motivated the creation of the DMI. Besides for documentary reasons, this information was intended to restrict the scope of our investigations to those works which were intentionally created (i) to be actually performed with rather than being just research investigations; (ii) to be performed with on a long-term basis.

Authors were invited to pick as many motivations as they wished from a list of seven entries; the results are presented in Table 2. To cluster the answers into groups we performed a principal component factor analysis with Varimax rotation (Kaiser Normalisation). Three components with an eigenvalue greater than 1.0 were found (the components loading are shown in Table 2).

Component 1 includes the DMIs designed as a research investigation. **Component 2** includes the DMIs designed

[3] `http://www.guthman.gatech.edu`
[4] The questionnaire and the results are available at `http://instrumentslab.org/SurveyAnswers.xlsx`
[5] `https://roli.com/products/seaboard-grand`
[6] `https://www.smule.com/sunset/magicfiddle`
[7] `http://www.alphasphere.com`

after the designer's need. **Component 3** suggests an inverse correlation between "To complement my artistic practice" and "As an assignment for school". Given the focus of this paper, we excluded from successive investigations the 15 DMIs whose motivations only belonged to those of Component 1 and those who were only intended "As an assignment for school".

Another question prompted the authors to indicate whether their DMI was ever intended to be used on a long-term basis; we excluded the 4 DMIs that were not. As a consequence of these two exclusions, the report discussed in the next sections was reduced to the 51 DMIs that have been originally designed for a prolonged use as a performance instrument.

3.2 Ongoing use

A number of questions directly investigated the ongoing use of the instrument. Figure 1 indicates the percentage of DMIs that are currently ready to performance; 47.1% are not. Of these, two thirds would require substantial work (more than a few hours) to be ready for performance.

Figure 1: Is the instrument ready for performance? If not, how long would it take to have it ready for performance?

Figure 2 indicates that the one third of the DMIs are available to buy or to hire. Sale information offers a similar figure. Only one out of five DMIs sold at least 1 unit. A notable difference exists between iOS apps and other DMIs. The number of sales for iOS apps (including free downloads) ranged from 1200 to 250000. If we exclude iOS apps, only 5 DMIs have ever been sold, 3 of which have been sold to more than one buyer. It should be noted, however, that in some cases the designers might have donated the DMI.

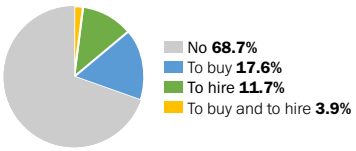

Figure 2: Is the instrument available to buy or hire?

Figure 3 shows that the 23.5% of the DMIs have been publicly performed 0 or 1 times; more than half of them at most 5 times. We then computed the average number of performance for year, normalised by the edition of NIME the paper was presented to.[8] On average, the 47.1% of the DMIs have been publicly performed less than once for year and only 11.8% have been performed more than 10 times per year.

Figure 4 shows that almost half of the DMIs have been played by fewer than 3 musicians; only one DMI out of five has been played by at least 10 artists. Another indicator of the uptake of a DMI is the number of ongoing projects in which it is used. In more than half of the cases (53.1%) there are no ongoing projects, though 10 authors indicated that there might be some that they do not know about.

[8]This data is an estimate as some DMIs were available even long before the paper presentation.

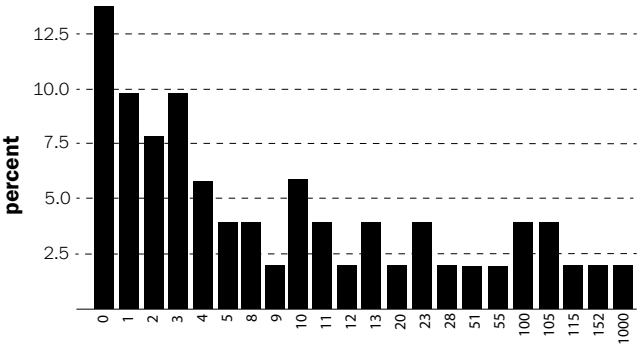

Figure 3: How many times has it been performed in public?

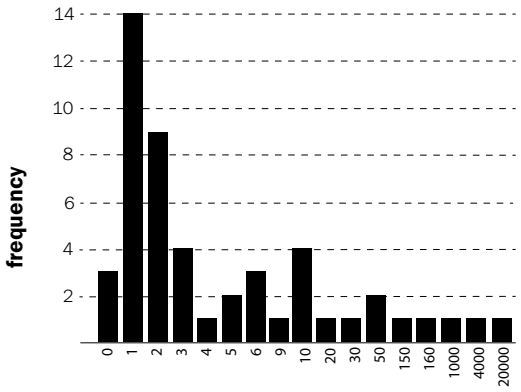

Figure 4: How many artists/musicians have worked with it?

3.3 Interface evolution

Authors were asked to elaborate whether and how did their initial intentions change; a third indicated they did.

In three cases, the target users changed. Two DMIs were initially intended for the authors' own composition but the interest of others convinced them to make it available for others. Conversely, one author was initially interested in making a general instrument but he later redirected his efforts to make an instrument for himself.

In six cases, the objective of the DMI changed. For instance, the p-bROCK digital bagpipe [16] was originally intended as instrument for performance and it is now about to be commercialised as a tool for learning.

In a few other cases, the evolution that the DMI underwent was caused by unexpected possibilities that emerged. This is the case for the Magnetic Resonator Piano [14], whose author reported that over time he discovered how the original intended outcomes were less interesting or less successful than he thought, but that some completely unexpected new sounds and techniques emerged.

In some cases, the author attributed the importance of the DMI presented at NIME as a formative event rather than as the conclusion of a project. For instance, the Hex Player [17] was only ever intended as a proof of principle: the intention of the author was to develop a better-performing instrument at a later date, something that has happened 5 years later. As another example, Dahlstedt reported that he carries the experience of developing Pencil Fields [5] with him; he uses what he has learnt from it into future instruments and mappings all the time.

This reflections are supported by the answer to one question that asked the reasons the authors attributed to the limited uptake of their DMI, if applicable (for this specific

Table 3: If it is not regularly performed or demonstrated now, what are the reasons?

Motivation	Freq.
"I don't have the opportunity at the moment"	22
"I turned my attention to building other DMIs"	14
"The hardware needs too much maintenance"	10
"It was a collaborative effort which has stopped"	9
"My musical interests no longer align with the capabilities of this DMI"	8
"I no longer work with DMIs"	6
"I was unsatisfied with the musical output"	5
"I was unsatisfied with the playing experience"	4
"I am working to an updated version of the DMI"	3
"The software needs too much maintenance"	3

question we extended the investigation to all the 70 answers). The answers are shown in Table 3. Of particular interest is the record describing that many had turned their attention to updated versions of the DMI or to other DMIs. To this respect, we further asked if other DMIs derived from the one presented at NIME. The 27.1% evolved into new version; in other cases it inspired other instruments built by the same author (8.5%) or by others (7.1%).

The figures presented in this section offer a picture of the uptake of the DMIs presented at NIME confirming what has been recognised by members of our community [10, 12] but never systematically pinpointed. Most of the DMIs that were originally intended to be performed on a long-term basis ended up being performed for a few exhibitions only.

4. DESIGN CONSIDERATIONS

This section proposes reflections about practices and processes of instrument design. Makers' diagnoses of design issues that limited the uptake of the instruments are integrated with considerations about their ample uptake. When applicable, these reflections are grounded on theories and practices typical of HCI.

4.1 Signature Features

An important element that seems to determine to a relevant extent the positive uptake of a DMI is the idiosyncratic attributes that it offers - what [19] defined as "signature features" and [20] called "unique identity." These attributes can either refer to the functionality or to the appearance of the DMI.

4.1.1 Functional

Three authors reflected that their DMI offered features that are completely new, that go beyond what was achievable before, that help achieving a particular goal in the authors' artistic practice, or that fulfil a specific need. For instance, the specific need fulfiled by the Quarterstaff [22], was *"to perform electronic sounds in a gestural way"*.

The uniqueness of the DMI was attributed by three authors to the idiosyncratic sound their DMI produces. An example is offered by McPherson when comparing his two augmented instruments: as opposed to the Magnetic Resonator Piano [14], which *"has a distinct sound world of its own, which has given composers a reason to use it"*, the TouchKeys [13] *"is a MIDI controller, it lacks its own sound. I have found the lack of a signature sound to be an impediment to its artistic uptake, especially among composers"*.

4.1.2 Aesthetic and craftsmanship

Five authors attributed the popularity of their DMI to its unique aesthetic: its look, its feel, its craftsmanship and woodworking, and its quality construction. Answering on what aspects of their DMIs they would improve, two creators indicated aesthetics, ergonomic, and build quality.

An idiosyncratic appearance also enables the DMI to stick out during a live performance. When discussing the positive aspects of his Manta [26], Snyder commented that *"it has a unique look and feel that sets it aside on stage"*. Similar comments were given about the E-Recorder [9]: *"it is nice to watch on stage"*, and The Talking Guitar [7]: *"it requires large gestures which are easy to interpret for the audience"*.

4.2 User-experience

User-experience design is one of the most common design processes in HCI. Its appropriateness for DMIs was advocated by Morreale and colleagues in their experience-oriented design framework [18]. Comments collected from the authors supported the centrality of musician experience in the design process of a DMI: seven DMIs achieved their positive uptake by addressing aspects of user-experience.

4.2.1 Familiarity

Three authors attributed the positive uptake of their DMI to having offered an intuitive instrument based on traditional modes of interaction. This is the case, for instance, of the TouchKeys [13], whose *"success is directly tied to its familiarity"* and of the Concept Tahoe [23], a microphone augmented with buttons to MIDI control that *"worked because it took a form factor that people were familiar with, and expanded upon it"*. The instrument did not invent completely new musical possibilities, but it *"made it easier or more elegant - people were already creating live-looped performances"*.

4.2.2 Simplicity of interaction

Having a simple interaction favoured the uptake of three DMIs. For instance, the isomorphic design of Musix [21] *"enabled everybody to interact with tonal music in an alternative way to traditional piano layout, exposing and simplifying harmony"*. As another example, the Pencil Fields [5] *"allowed for embodied playing on an instrument which is otherwise hard to control in that way"*.

4.2.3 Set-up time

A long preparation time might hinder the will of the musician to pick up the DMI. Leeuw brought this issue to the fore when reflecting on his Electrumpet [11]: *"it is not ready out of the box like my normal trumpet is"*.

4.3 Technology

This section offers discussions about authors' fortunate and erroneous choice of hardware and software.

4.3.1 Common platforms

Both developers of mobile apps and designers of tangible DMIs suggested to choose commonly available platforms. The former agreed unanimously that iOS is preferable to other platforms as it offers a solid user base that is receptive to new instruments. The latter suggested to design for commonly available devices rather than creating new hardware or using less commonly available hardware. This suggestion extended to using more typical audio platforms - as Axoloti[9], Bela[10] [15], or Teensy[11].

The platform should also be easy to keep up to date and ready to perform. Snyder suggested that he would possibly *"make a bootloader to allow the user to upgrade the firmware*

[9] `http://www.axoloti.com`
[10] `http://www.bela.io`
[11] `https://www.pjrc.com/teensy/`

remotely" for the Snyderphonics Manta [26]. This concern was shared by the 41.2% of the authors: their ability to set up and run the system is currently tied to an old version of specific software that does not reliably run any longer. To have the instrument ready for performance they should upgrade (32.4%) or even downgrade (8.8%) the OS or other software.

4.3.2 Open-source

With the exception of those operating in the mobile domain, a general consensus endorsed the use of open-source software and hardware platforms. Donnarumma, for instance, attributed part the popularity (more than 1200 units sold) of the XTH Sense [6] to being open-source.

Four other authors, when reflecting of what they would have done differently, indicated that they would choose open-source solutions. Sentürk elaborated that his Kinect-based interface [25] would have been more enduring if it had been open-source: *"it is more sustainable, it allows derivatives and offers inspiration to proliferate"*. A similar argument was made for the Snyderphonics Manta [26]: avoiding vendor-specific HID protocol would free the creator to continue to support translation software for it.

4.3.3 Portability and low latency

The comments of seven authors supported previous research findings that portability and low latency are important features for the uptake of audio applications [19]. While the importance of low latency was explicitly mentioned by one author only, six authors elaborated on the need for self-containedness, which makes an instrument always ready to use and play without the need to connect it to a computer. Van der Torren explicitly indicated self-containedness as *"the main reason for the success of Striso"* [28]. Snyder reported that future implementations of the Birl [27] will be self-contained so that it won't *"need to interface with a multimedia computer (which will inevitably change and be updated down the road)"*. Similarly, Gabana suggested that he would modify his Radear [1] to make it self-contained.

4.3.4 Modularity

Five authors pointed out the importance of having a modular structure in hardware, software, and coding procedures. This would allow the DMI to be more easily fixed, updated, and expanded. The modularity argument was brought up also for what concerns the very category of DMI: when reflecting on the limited uptake of his augmented keyboard [31], Wierenga reported that he *"moved away from working with a single virtuoso instrument and toward a multiplicity of smaller modular instruments"*.

4.4 Musical possibilities

Four authors reflected on the musical possibilites offered, or not yet offered, by their DMI.

4.4.1 Ownership

DMI frameworks exist that suggest that the execution and the identification of unique playing styles should be supported in instrument design by means of personalisation [18, 29]. This concept was elaborated by Snyder when talking about the Birl [27]: *"The ability for a performer to train the instrument to his or her own control mapping preferences (such as fingerings for certain pitches) was particularly useful for musicians playing the Birl"*.

4.4.2 Subtle control

Two authors identified the lack of subtle control in their DMI as the cause of its limited uptake. Even in cases of ample uptake, a subtler control would entail deeper sound manipulation, which, as reported by Grossman, was not possible when the E-Recorder [9] was created in 2000 but it would be now feasible.

4.5 Design process

Comments from eleven authors referred to design decisions that were taken, or not taken. In this section we grounded these reflections on design concepts typical of HCI.

4.5.1 Scenario development

Related work on HCI [2, 4] and NIME [18] suggests to start the design process from scenarios identification and high-level user stories development. This excercise helps designers to "clarify implicit assumptions, raise design questions, suggest design solutions" [2], and to "to reflect upon the kind of experience they wish to offer" [18].

Collected comments evidenced a general lack of care in the development of design scenarios. Two authors attributed the lack of uptake of their DMI to not having properly elaborated scenarios for performing with their instrument. In the case of The Talking Guitar [7], for instance, Donovan acknowledged not having sufficiently considered *"the practicalities of performing with the instrument, in particular about the constraints imposed by the tech"*.

4.5.2 Participatory design

Participatory design is an approach to design that involves the users destined to use the system to play a critical role in designing it [24]. Working with final users at early stages of design promotes their skills and experiences as a resource for design.

Six creators endorsed the advantages of working with the final user at early stages of design. Working with final users is particularly important when working with less familiar instrument paradigms, as elaborated by Snyder when discussing the design process for the Birl [27]: *"I am not a wind player, I needed to gather more feedback about the ergonomics of the instrument, and the needs of players"*.

Empowering users to have a say in the design process also helps identifying possible pitfalls, as in the case of the Gamelan Sampul [32]. The gamelan musicians that worked with the author turned down the proposed solution as they mistrusted technology: they feared electronic musical instruments would take over the classical gamelan world.

4.5.3 Prototyping

A possible limit of participatory design is expressed by Snyder, who involved users in the design of the Birl [27]: *"many things that players said they wouldn't like wound up being things they liked once I had implemented them and they were able to try them out. So I'm not sure how much stock I should give this feedback until I have testable prototypes"*. This statement highlights the importance of prototypes when designing new DMIs, as seconded by Mamedes when describing how differently would he develop his Intonaspacio [12]: *"I would try to have several iterations of the prototype and have more people to try it out (analysis gestures) before creating a final performance version."*

4.5.4 Market Analysis

Market analysis offers another way to sense what the user response could be. One author reported that a well-known company operating in music technology may pick the DMI back up again, *"but in the meantime they are attempting to find evidence that the market is big enough to be worth further investment"*.

5. FINAL REMARKS

This paper provided evidence to the prevalent feeling that most DMIs fail at the longevity exam [10, 12]. This paper addressed this issue by proposing a bottom-up approach that generated insights to assist creators' design by learning from good practices and mistakes of past DMIs.

Our contribution should not be intended as another DMI design framework, neither as a receipe book to meticulously follow when designing new musical instruments. Rather, it should be intended as a repository of DMI creators' reflections on their own practice, which we elaborated into practical design considerations. These considerations highlight factors that future designers can use to make their designs more enduring, and pitfalls they can avoid.

Findings presented in this paper also suggest that some of the DMIs are indeed discontinued in their original version but, nevertheless, they contributed by informing future work. In any new enterprise many new products fail but are inspirational; in academia, research papers rarely represent the final word on a subject; in contemporary composition, many pieces are not played more than once or twice. In each case it is an expected and normal outcome that most creations do not have staying power.

This reflection opens a debate: is *non-continuation* necessarily a sign of failure of DMIs? What should the community's expectations be for instruments to continue to be used? We believe that our responsibility as the main academic hub of DMI design is to pick up these challenges and establish NIME as the home of this debate.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

[1] D. G. Arellano and A. McPherson. Radear: A tangible spinning music sequencer. In *NIME*, 2014.

[2] D. Benyon and C. Macaulay. Scenarios and the hci-se design problem. *Interacting with computers*, 14(4):397–405, 2002.

[3] V. Braun and V. Clarke. Using thematic analysis in psychology. *Qualitative research in psychology*, 3(2):77–101, 2006.

[4] J. M. Carroll, editor. *Scenario-based Design: Envisioning Work and Technology in System Development*. John Wiley & Sons, Inc., New York, NY, USA, 1995.

[5] P. Dahlstedt. Pencil fields: An expressive low-tech performance interface for analog synthesis. In *NIME*, 2012.

[6] M. Donnarumma. Music for flesh ii: informing interactive music performance with the viscerality of the body system. In *NIME*, 2012.

[7] L. Donovan and A. McPherson. The talking guitar: Headstock tracking and mapping strategies. In *NIME*, 2014.

[8] C. Erkut, A. Jylhä, and R. Disçioglu. A structured design and evaluation model with application to rhythmic interaction displays. In *NIME*, 2011.

[9] C. M. Grossmann. Developing a hybrid contrabass recorder resistances, expression, gestures and rhetoric. In *NIME*, 2010.

[10] S. Jordà. Digital instruments and players: Part ii–diversity, freedom and control. In *Proceedings of the International Computer Music Conference*, pages 706–710, 2004.

[11] H. Leeuw. The electrumpet, a hybrid electro-acoustic instrument. In *NIME*, 2009.

[12] C. R. Mamedes, M. Wanderley, and P. Ferreira-Lopes. Composing for dmis-entoa, music for intonaspacio. In *NIME*, 2014.

[13] A. McPherson. Touchkeys: Capacitive multi-touch sensing on a physical keyboard. In *NIME*, 2012.

[14] A. McPherson and Y. Kim. Augmenting the acoustic piano with electromagnetic string actuation and continuous key position sensing. In *NIME*, 2010.

[15] A. McPherson and V. Zappi. An environment for submillisecond-latency audio and sensor processing on beaglebone black. In *Audio Engineering Society Convention 138*. Audio Engineering Society, 2015.

[16] D. Menzies and A. McPherson. An electronic bagpipe chanter for automatic recognition of highland piping ornamentation. In *NIME*, 2012.

[17] A. J. Milne, A. Xambó, R. Laney, D. B. Sharp, A. Prechtl, and S. Holland. Hex playerâĂŤa virtual musical controller. In *NIME*, 2011.

[18] F. Morreale, A. De Angeli, and S. O'Modhrain. Musical interface design: An experience-oriented framework. In *NIME*, 2014.

[19] F. Morreale, G. Moro, A. Chamberlain, S. Benford, and A. McPherson. Building a maker community around an open hardware platform. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*. ACM, 2017.

[20] D. Overholt. The musical interface technology design space. *Organised Sound*, 14(2):217–226, 2009.

[21] B. Park and D. Gerhard. Rainboard and musix: Building dynamic isomorphic interfaces. In *NIME*, 2013.

[22] J. C. Schacher. The quarterstaff, a gestural sensor instrument. In *NIME*, 2013.

[23] D. Schlessinger. Concept tahoe: Microphone midi control. In *NIME*, 2012.

[24] D. Schuler and A. Namioka. *Participatory design: Principles and practices*. CRC Press, 1993.

[25] S. Sentürk, S. W. Lee, A. Sastry, A. Daruwalla, and G. Weinberg. Crossole: A gestural interface for composition, improvisation and performance using kinect. In *NIME*, 2012.

[26] J. Snyder. Snyderphonics manta controller, a novel usb touch-controller. In *NIME*, 2011.

[27] J. Snyder and D. Ryan. The birl: An electronic wind instrument based on an artificial neural network parameter mapping structure. In *NIME*, 2014.

[28] P. T. van der Torren. Striso, a compact expressive instrument based on a new isomorphic note layout. In *NIME*, 2014.

[29] I. Wallis, T. Ingalls, E. Campana, and C. Vuong. Amateur musicians, long-term engagement, and hci. In *Music and human-computer interaction*, pages 49–66. Springer, 2013.

[30] M. M. Wanderley and N. Orio. Evaluation of input devices for musical expression: Borrowing tools from hci. *Computer Music Journal*, 26(3):62–76, 2002.

[31] R. Wierenga. A new keyboard-based, sensor-augmented instrument for live performance. In *NIME*, 2012.

[32] A. Wiriadjaja. Gamelan sampul: Laptop sleeve gamelan. In *NIME*, 2013.