What Makes a Good Musical Instrument? A Matter of Processes, Ecologies and Specificities

Matthew Rodger, Paul Stapleton, Maarten van Walstijn, Miguel Ortiz, Laurel Pardue
Sonic Arts Research Centre
Queen's University Belfast
{m.rodger, p.stapleton, m.vanwalstijn, m.ortiz, l.pardue}@qub.ac.uk

ABSTRACT
Understanding the question of what makes a good musical instrument raises several conceptual challenges. Researchers have regularly adopted tools from traditional HCI as a framework to address this issue, in which instrumental musical activities are taken to comprise a device and a user, and should be evaluated as such. We argue that this approach is not equipped to fully address the conceptual issues raised by this question. It is worth reflecting on what exactly an instrument is, and how instruments contribute toward meaningful musical experiences. Based on a theoretical framework that incorporates ideas from ecological psychology, enactivism, and phenomenology, we propose an alternative approach to studying musical instruments. According to this approach, instruments are better understood in terms of processes rather than as devices, while musicians are not users, but rather agents in musical ecologies. A consequence of this reframing is that any evaluations of instruments, if warranted, should align with the specificities of the relevant processes and ecologies concerned. We present an outline of this argument and conclude with a description of a current research project to illustrate how our approach can shape the design and performance of a musical instrument in-progress.

Author Keywords
Musical instruments, Musicians, Evaluation, Ecological Psychology

CCS Concepts
• **Human-centered computing** → **Interaction design** → Interaction design theory, concepts and paradigms; • **Applied computing** → **Sound and music computing**; Performing arts;

1. WHAT MAKES A GOOD MUSICAL INSTRUMENT?
This question may seem trivially easy to answer. Or perhaps it seems a misguided thing to ask in the first place. If the former, a little reflection should reveal problems with any seemingly simple or comprehensive response. *'It should be playable' = 'By whom?'; 'It should be easy to learn' = 'Ever heard of the violin?!'; 'It should allow for musical expression' = 'Can every meaningful thing that musicians do with instruments be called 'expression'?''*. Almost as quickly as answers can be generated, counterexamples appear, or important conceptual shortcomings are identified. For these reasons, one might adopt the second response of dismissing the question itself. However, this would overlook some challenging but potentially fruitful lines of enquiry that the question demands for those who design, perform with, compose for and otherwise engage with musical instruments. (Note: we intentionally do not distinguish between different classes of instruments, including those that make exclusive or hybrid use of acoustic, mechanical, electronic or digital materials.) The position of this paper is that expanding the conceptual tools for understanding this question beyond those inherited from traditional Human-Computer Interaction will be productive for understanding musical instruments in their specific contexts.

NIME'20, July 21-25, 2020, Royal Birmingham Conservatoire, Birmingham City University, Birmingham, United Kingdom.

2. LIMITATIONS OF THE DEVICE, USER, & EVALUATION FRAMEWORK
A seemingly useful framework to unpack the opening question, borrowing concepts from traditional HCI, is to think of a musical instrument of the type typically associated with NIME as a device, with an intended user, which can then be evaluated on the extent to which the instrument-as-device effectively supports the musician-as-user execute some functional task (e.g. conveying the nostalgia of the changing seasons to a packed audience of hopeless romantics). This framing of what a musical instrument is may have proved useful for some lines of investigation and can still be accommodated within the framework proposed here under specific circumstances. However, each component of this framework has inherent limitations when considering musical instruments, the different contexts in which they are engaged with, and the different meanings enacted by musicians with instruments. These limitations, along with arguments for different approaches within HCI (e.g. [14,29]), as well as in NIME and related fields (e.g. [3,13,15,19,33]), motivate us to explore a more expansive conceptual framework.

2.1 Instrument-as-Device
In regarding musical instruments as devices, there is a risk of two conceptual cul-de-sacs. The first is the implication that an instrument is a singular entity with a set of intended functional behaviours, known to the designer and employed by the user for the purpose of attaining some practical goal. Consequently, the success or failure of a device can be assessed by the extent to which it supports the attainment of these pre-determined goals. That is, its global function and dysfunction can in theory be defined prior to any actual user interaction. This is a highly restricted view of the different ways musicians play with instruments, and in some cases an inaccurate representation entirely. Consider 'extended technique', i.e. the playing of an instrument in a manner that differs from its design. This is a longstanding and common practice in many forms of music making, e.g. "col legno" (playing a stringed instrument with the wood of the bow rather than the hair), which dates at least back to the 17th century [4]. The idea that the instrument-as-device should be assessed by how readily it supports its intended design function is also challenged by the notion of 'instrument resistance', by which the effortful-ness of playing an instrument may be a source of creativity and animation of performance. Simon Waters describes the oddities of early flute designs and associated playing challenges, but argues that "it is precisely the difficulties, the resistances, … which give the repertoire its character and 'meaning'." [34]. Easy execution of predetermined functions is an inappropriate description for either of these examples.

A second and related limitation of the instrument-as-device framing is the implicit independence of function from the history of its form and context of engagement. A device should support a user in carrying out a task and the history of how it arrived at its current configuration to do so is far less important than whether it performs the relevant task-supporting functions; it either does the job or it doesn't. Moreover, the

success or failure of a device to perform a function generally does not depend on the socio-cultural context in which it is used. In most cases, one should probably not use an angular saw in a public library but doing so does not mean that the saw itself is broken. In the case of a musical instrument, the history of selection processes that have shaped the current instantiation (including intentional but also implicit, distributed design 'choices') can have important consequences for what it 'does' and 'means' for those who play it. Likewise, the functional behaviours of a musical instrument and the socio-cultural context in which it is played are far more entangled than the concept 'device' would typically imply. An illustration is the co-constitutive relationship between the saxophone and Jazz music making. Adolphe Sax certainly did not foresee John Coltrane's use of multiphonics and overtone playing which recast "instrumental deficiencies" as enablers of new techniques that went on to be emblematic of the Jazz idiom. All such sax timbres would make little sense outside of the complex temporal-socio-cultural context of Jazz, or other forms of music influenced or responding to Jazz. As a result, it is now difficult to hear nearly any sax or sax-like timbre and avoid the connotation of Jazz, even while the definition of the idiom is far from stable [6].

2.2 Musician-as-User

Another set of conceptual issues arise from characterising musicians as users of musical devices. Firstly, musicians vary in their capacities and histories of embodied knowledge (between each other but also within themselves across nested timescales of learning and experience), which alter the corresponding nature(s) of the instrument for them. The same guitar will offer different potentialities for an accomplished flamenco player than for a child picking it up for the first time. Indeed, the functional properties of a given instrument can only be meaningfully understood relative to the effective capabilities of a specific musician at a specific period in her musical development and personal history. Thus, there may be no such person that can be picked out as the instruments' 'prototypical user'.

A second issue with the musician-as-user approach is the situationally embedded nature of musical activities. What a musician does with the instrument is hard to make sense of if divorced from both the immediate and extended socio-cultural context in which she is acting. As in the saxophone example above, it is not just the instrument that relies on a musical cultural tradition to have meaning, but also the actions of the player. This is the case even when bending or breaking musical cultural norms, as such transgressions are only legible within a given musical context. The idea of a musician 'using' a 'device' does not inherently accommodate the bidirectional influence of musicians with their musical and interpersonal environments, which shape and guide the interactions between musician and instrument beyond what can be captured by functional descriptions of either alone. In fact, there are many instances in which optimal functional usability is not even a desirable characteristic of a musical instrument. Musical performances in which an instrument facilitated successful execution of the performer's task with minimal effort might be evaluated as 'stale', 'clinical' or 'boring'. Indeed, some musicians may actively try to counteract the optimal functioning of the instrument. In such cases, should we say the musician has used the device incorrectly?

2.3 Evaluation of User Devices

The concept of evaluation would seem to flow straightforwardly from the ideas of a device and a user. You have a prototypical user who needs to accomplish some task, a device designed to support achievement of this task, and you should evaluate whether the device does in fact support an exemplar user in doing this. If it does, it's good to go; if it doesn't, more work on the part of the designer is required. Other secondary qualities like 'ease-of-use' or 'user preference' might also be measured towards evaluating a device or comparing different devices that share functional purposes.

In the context of new musical instruments, the role and purpose of evaluation is complicated by the issues identified above. Instruments can do and mean many different things that are not easily delimited by a predetermined functional teleology, and this is affected by their evolution among other instruments and musical practices. Musicians are too varying to allow for the characterisation of a prototypical user, and the messy bi-directional influences between musicians and their socio-culturally situated contexts disrupts any neat mappings between musicians' intentions and instrumental functions. Indeed, it becomes clear that it is not possible to come up with a 'canonical' evaluation of a given new musical instrument given the various ways that these things interact across different timescales and situations. Some of the complications inherent in evaluating digital musical instruments have already been discussed by others [2,16,18,19]. Our concern here is to expand our conceptual ontology for considering what makes a good musical instrument by incorporating insights from different-but-interrelated fields of enquiry: ecological psychology, enactive philosophy of cognitive sciences, and phenomenology of skill.

3. BACKGROUND AND RELEVANT CONCEPTS FROM ECOLOGICAL PSYCHOLOGY AND NEIGHBOURING FIELDS

One school of thought which informs our approach to studying new musical instruments is ecological psychology [5,10,12]. There is not sufficient scope to provide a full overview here, but two key premises of ecological psychology for current purposes are: the *reciprocity* of organism and environment; and the corresponding tight coupling between perception and action.

The first key premise is rooted in the recognition that the language of physical sciences is not the only scientific means of describing state-of-affairs; an equally valid description of the world can be given at the ecological scale. The language of physics is intentionally independent from the perspective of any particular observer – e.g. a solid, extended mass reflecting beams of photons. However, an ecological description of the same situation is specific to an organism of a particular species (hereafter 'agent') – e.g. a supportive surface which structures the ambient light array sufficiently to be perceived as such by an animal of a certain weight with a visual system. This entails a shift from thinking of a physical universe in scale-free units, to an environment specific to a species with its embodied morphology and evolutionary history. The latter is no less 'objective' than the former, but it necessarily includes a perspective. The physical extension of liquid shows up differently in the environment of a water boatman insect than it does in the environment of a collie dog. Thus, the reciprocity of agent and environment – the description of one entails the description of the other and each is specific to the other. Because of this, ecological psychologists consider the agent-environment system the appropriate target of psychological scientific study, rather than carving them apart and dissecting one without reference to the other.

The second key premise is the rejection of a passive serial process from sensation (via thought) to motor response as explaining animal and human behaviours. Ecological psychology follows in the earlier steps of Dewey [8] in rejecting this picture in favour of one which starts with an active, seeking agent as the precursor to perception. As Dewey argued, identifying when the process of perceiving begins and ends is not unproblematic: did the child perceive the flame when she recoiled her hand, when she reached out to touch it prior to that, when she saw the bright light before then, when she turned her head and eyes before that? In accepting this temporal extension of perception, one sees that perceiving and moving are (in most living creatures) part of an ongoing, overlapping *looping function*. For example, stepping forward shifts our optical field outwards from the point of heading, which provides information about the direction and rate of walking, which in turn can guide subsequent stepping actions. In walking to a distal target, the gap to close may be perceived in terms of the steps required to cover it rather than body-scale-free dimensions (such as metres). These points lead to the observation that our senses and motor behaviours need to be viewed as dynamic systems which overlap in

their anatomical and functional components [11,23]. For example, the *visual system* comprises the eyes, connected to the brain, in a moving head on a locomotory body.

A consequence of combining these premises is the concept of 'affordance', introduced by James Gibson to account for what it is that populates the environments of active perceiving agents. A subset of the physical description of the world can be re-described in terms meaningful to a particular agent with its specific embodied form and action capabilities. For example, the water described above may be a pathway to cross for the water boatman insect or a puddle to splash in for the collie dog. The same physical entity *affords* supported locomotion for one agent but 'splash-ability' for the other. Because organisms are fundamentally active perceivers and because it is through the looping function of perception and action that organisms are in contact with the world, it is the affordances of the environment (including 'tools' in the broadest sense) that are primarily perceived. The cup is not perceived primarily in abstract spatial dimensions (e.g. centimetres or inches). Rather, it is perceived primarily as graspable, liftable, drinkable-from, and so on. Moreover, these properties are only perceivable to creatures with visual systems attached to arms with hands at the end including opposable thumbs, pressure sensitive organs in the finger pads, and so on. Affordances are properties of the world that can only be picked out relative to agents with corresponding embodied capacities to act on them (sometimes called '*effectivities*' [30]). A cup placed too close to the edge of a table and toppling may be perceived as catchable only to someone with the capacity to quickly close the spatio-temporal gap between their open hand and the toppling cup. Among members of the same species, some agents will have access to and be capable of acting upon more (or a different set) of affordances than others, as a function of their skilful abilities.

The relationship between individual action capabilities and affordances led Baggs & Chemero [1] to note that Gibson's conception of the environment could usefully be further subdivided into the habitats of species, and the Umwelts (from von Uexkull, [32]) of individuals. The habitat consists of affordances that a typical member of a species would be capable of interacting with (e.g. graspable objects, walkable distances, etc.), whereas the umwelt consists of the affordances specific to the capacities of a particular individual, their history of dispositions and skills (e.g. the kit and two sticks on a stage for an experienced drummer). The Umwelt concept thus allows for understanding the personal perspective/filtering of the available affordances for/by a specific agent. The discussion of the distinction between habitat and umwelt represents an effort by Baggs and Chemero to resolve a tension between ecological psychology and the separate-but-related approach to agents and their activities in their environments of *enactivism*.

Enactivism shares ecological psychology's emphasis on the processes of active sensing agents coupled to their environments (e.g. [31]). Where it differs is its greater emphases on co-creation of agents and their environments, the phenomenology of meaning as emerging from sensorimotor engagement with the world, and the constitutive roles that interactions between different agents play in forming minds and shared meaning. Agents and environments are taken as not merely *reciprocal* (i.e. causally related to each other), but as *co-constituting* (i.e. mutually forming each other). Meaning is neither inherent in the objects and structures in the world, nor imposed by agents through representing the world, but rather is constructed through the bidirectional interactions of agents with their environments. Enactivism also emphasises the intensely interpersonal nature of our experiences and behaviours. The concept of 'participatory sense-making' [7] has been introduced into enactivist discourse to explain the highly inter-subjective nature of how we act, how and what we learn, and the complex of socio-cultural interactions that shape even our seemingly 'rudimentary' behaviours.

At the interface between ecological psychology and enactivism, taking inspiration from the phenomenological works of Merleau-Ponty and Hubert Dreyfus, are a number of researchers who aim to elucidate the ways that humans spontaneously and (mostly) successfully navigate their complex physical/social/cultural environments (e.g. [26]). In a basketball game, the player holding the ball tunes into the subset of all possible actions which are legal within the rules of the game. An experienced driver can hold a conversation about politics while simultaneously steering the vehicle through city streets. These examples show that coordinating actions in relation to the affordances of the environment entails selecting out of the multiple available opportunities those that achieve our practical and social aims, often simultaneously [24]. Moreover, this skilful engagement often occurs 'prereflectively' [25], i.e. without first requiring conscious deliberation about how best to act. Indeed, the fit between our actions and the socio-cultural environment is not only a result of skilful behaviour, but conversely the socio-cultural environment is a field of forces which shapes the development of skilful behavior itself [24]. What we choose to do and what we can do is largely determined by what we have learned to do, which in turn is shaped and filtered by what we have observed can be done and is typically allowed (in different types of socio-cultural settings). This highlights the bi-directional influences of processes which might be intuitively analysed at the level of perception-action and those which might seem to be 'purely' socio-cultural. The targets of different modes of analysis interact with and influence each other in complex ways.

4. PROCESSES, ECOLOGIES AND SPECIFICITIES

We now revisit the problems posed by the question of what makes a good musical instrument with an alternative conceptual arsenal to that provided by traditional HCI.

4.1 Processes rather than Devices

To avoid the issues associated with treating musical instruments as devices, we should jettison the idea of an instrument as an essentialised singular thing, but rather think of it as a constellation of *processes* (affordances) which may be shared with other instruments, and which may change over time. The instrument as bundle of affordances accommodates the idea that the instrument may mean different things to different musicians (as a function of their individual effectivities and developmental histories). As an example from NIME, in discussing her experiences from playing the Hyper-Flute over many years, Palacio-Quintin [20] describes how some additions to the functional processes of the instrument through motion-sensor-to-sound mappings required extensive time and learning to effectively control in performance. That is, the development of corresponding effectivities was required to act upon the new affordances of the instrument. Moreover, affordances can interact with and constrain each other as a function of the coordination required to act upon them concurrently. What the instrument affords is not a linear sum of its sonic capacities.

Our approach can also side-step the implied functional teleology of the device concept. A designer may (attempt to) implement certain affordances to facilitate specific task aims, but the affordance concept by itself does not require that this (ever) be the case. A tree stump can afford sitting for a human, jumping onto for a squirrel, and hiding behind for a mouse - whether it was designed to support all these activities for each of these agents is nonsensical. In a musical context, the prepared piano shows how the affordances of an instrument are not predetermined by the designer [22]. Placing a heavy object on the strings may change the key-able affordances of pitched sounds to juddering percussive ones, while getting under the lid unwraps affordances not available being sat at the keyboard. These dispositional properties were features of the piano prior to their discovery but were not part of the piano's design.

In addition to comprising a conglomerate of dispositional processes (affordances), the instrument is also a part of a network

of external processes, including musicians' development and learning, style formation and evolution, cultural creation and history. Taking a snapshot of these things may serve some practical purposes for the sake of analysis or reflection, but it would be a mistake to assume in so doing that these have been frozen in time or that they ever could be. An example is the evolutionary history of keyboard instruments, starting with the hydraulic organ from Greek antiquity, then onwards (and outwards) to the harpsichord, carillon, pianoforte, Hammond organ, Moog synthesizer, and so on [4]. The Moog did not evolve directly from the Hammond, but like humans and chimpanzees, they share common ancestors. An account of the history of an instrument and selective processes operating on its design can be informative for understanding its current place in specific musical ecologies.

4.2 Ecologies rather than Users

If the above arguments that musical instruments are better thought of in terms of processes hold, it follows that for a given musical instrument there is no prototypical 'user'. The ecological and enactive approaches emphasise the reciprocity between agent and environment and so the multiplicities of instrumental processes have counterparts in multiple (actual or potential) agential effectivities and skillful behaviours. This is perhaps the most straightforward sense of *ecology*: a system comprising an agent and environment. In this case, between a particular musician and their individual capacities to engage and interact with a given instrument (i.e. the constellation of affordances it instantiates). To use the example from the previous subsection, the ecology formed by Palacio-Quintin and the Hyper-Flute is different from one formed by an inexperienced flautist and the same instrument.

A broader sense of ecology comes from recognising that no agent is an island, but rather a member of a community of agents and that community shapes the capacities and dispositions of the agent (as well as that of the instrument). Again, Simon Waters [33] illustrates this idea nicely:

"Although the modern Boehm clarinet is 'designed' as an equal temperament device, this cultural expectation is carried as much in the performer's body as in the acoustic system of the physical object, and in the hands of a South Indian musician the same device affords entirely idiomatic delivery of a music which is subject to entirely different principles (of pitch subdivision and much else)."

All these factors may need to be considered in understanding the meaning and practical value that a given instrument has for a specific musician in a specific situation.

4.3 Specificities Determine Evaluations

A consequence of the above arguments is that the idea of evaluating instruments as user devices using some generalised methodology becomes untenable. As has already been discussed by [19], there are multiple possible stakeholders for a new musical instrument with different possible evaluative concerns (e.g. performer, audience, etc.), and different qualitative dimensions across which evaluative judgments might be mapped (e.g. robustness, playability, …). If one takes seriously the complex multi-way interactions between the instrument's teeming affordances, the musician's repertoire of effective actions to engage these, her skill in coordinating these actions within the unfolding musical situation, the fit or tension between all these and the broader socio-cultural-historical setting, then the aim to perform any conclusive generalisable evaluation seems fanciful. What instead should the role and justification for any evaluation be?

Here we think that the concept of *specificities* can play an important role in drawing attention to the specific configurations of instrument, musician-as-agent, and ecological contexts that could differentially be described, measured and/or analysed. In introducing the term 'specificities' into this discussion, we draw from how the term is used in different technical contexts. In Biology, it is defined as "the narrowness of the range of substances with which an antibody or other agent acts or is effective", while its use in medicine is "the extent to which a diagnostic test is specific for a particular condition, trait, etc." [35]. These might be translated for present purposes as 'the effective components of the musician-instrument system relative to the relevant musical activities and contexts of interest'.

In a sense, the term 'specificities' combines the preceding concepts of processes and ecologies. An instrument can be reconsidered as a multitude of dispositional processes, a subset of which are accessible to a musician with the reciprocal effective capabilities (the instrument's affordances for that musician). The instrument itself is embedded in processes of design, selection, alteration and repurposing, which affect its apparent and latent behaviours. The musician+instrument form an interactive system with a history, and this system is enmeshed in a broader network of other musicians, instruments, perceivers, actors, and their histories. At each stage of this story, different links and directional effects might be observed and interrogated to suit different aims. But any complex system is not reducible to its parts and the tightrope between precise analysis and distorted representation is ever present. This is why we propose that it is important to identify and describe the specificities of parts and processes involved at multiple levels.

A consequence is that any evaluative method must be comparably specific, as must the purpose of the evaluation. This does not entail that evaluation is useless for critical analysis, or to extend understanding. Rather, for evaluation to be effective it must be considered what processes and their aspects are being interrogated, what features of the relevant ecologies are likely to be playing an effective role, and how will the outcomes of such evaluations feed back into the processes and ecologies of the instrument subsequently. In some cases, a comparatively reductive methodology may align with these considerations while minimally distorting the phenomena of interest. For example, latency of computational processes in a digital musical instrument can affect perception and playability of the instrument, and can be quantitatively measured and diagnosed with relative precision [17]. However, it is worth noting that the effects latency can have on musicians' performance or audience perception is not necessarily consistent across different musical styles, contexts and instruments, so even this reductive diagnostic should consider these specificities in evaluation. In other cases, reductive or context-independent analyses may not be possible, and so either different methodological approaches will be more appropriate, or indeed the goal of evaluation may need to be replaced with a different aim, such as discovery.

5. VODHRÁN: HISTORY AND MULTIPLE SPECIFICITIES OF AN INSTRUMENT-IN-PROGRESS

In the spirit of the approach outlined above, we now describe the ongoing developmental process of a musical instrument known as Vodhrán in terms of antecedent research activities and interdisciplinary motivations that led to its creation, as well as the situated context in which it is currently performed and studied. This description is not presented to validate our approach, but as an example of how the approach has shaped the design of an ongoing project. We conclude by pointing toward our aspirations for how this instrument could open up future artistic and scientific research processes that aim to (re)shape our understandings of what makes a good musical instrument.

5.1 Origin Story

Vodhrán was born from dialogue between researchers involved in two previous interdisciplinary research projects taking place at the Sonic Arts Research Centre (SARC). One project brought together the fields of engineering, instrument design and music performance to investigate physical modelling with real-time parametric tunability to create complex musical interactions. The other was developed by researchers in psychology and music to study movement sonification in motor skill learning. We give a brief account of each project before discussing their convergence from which Vodhrán developed.

The first project was motivated by a desire to create virtual-acoustic instruments that have the sonic material familiarity of acoustic instruments, while also allowing for real-time transformations and reconfigurations of the Newtonian properties of the instrument in ways not possible outside of the digital domain. For example, imagine the sound of a violin being played where the stiffness of the bridge gradually decreases over time while the material of the soundboard slowly phases between maple wood and stainless steel. The instrument may still sound "violin-like" although perhaps having an uncanny quality. The designed instrument known as VASBPI was based on a string-bridge plate model excited by a string-board interface with 32 adjustable parameters controlled by individual knobs. A study of how experienced musicians interacted with the parameters of the instrument revealed two (non-exclusive) modes of engagement:

1. *exploratory*: actively testing out the affordances of the instrument in relation to each musician's apparent capabilities and curiosities;
2. *performatory*: deployment of specific musician-instrument configurations including techniques, gestures, and longer-scale compositional and/or improvisatory strategies [28].

The musicians moved between exploratory and performatory modes of engagement during extended periods of interaction with previously unfamiliar musical instruments, revealing a process of discovery, expectation and confirmation (or otherwise), leading to further 'exploratory information seeking'. The instrument was also played and further developed "in the wild" through an artistic research project which incorporated VASBPI into professional improvised music contexts [27]. The project identified areas for further research, including improving the method of interaction for specific parameters of the model (i.e. damping and excitation position), and engaging more deeply with how experienced and novice musicians learn to play complex physical modeling-based instruments. From the current approach, this project highlights how the affordances of the instrument are interactive processes of the musician-instrument system, and that musicians' selected affordances transform with time and the context of the musical activity.

The other antecedent research project was about movement sonification as augmented feedback for motor skill acquisition. Experiments measured participants learning a bimanual coordination task with or without self-generated feedback in the form of sounds triggered or modulated by participants' movements [9]. Augmented feedback effectively set up modified perceptual-motor task systems depending on the sonification condition, which did or did not enhance motor learning as a function of the characteristics of these systems. This can be interpreted as demonstrating that learning of instrumental actions or techniques (effectivities) can be driven by the auditory effects of those actions (affordances). Hence, the acoustic 'materials' and how actions excite/modulate them shapes acquisition of instrumental motor coordination, which in turn establishes the range and types of affordances available to the learner for subsequent performance. The design of an instrument cannot necessarily dictate the process of learning to become a coupled musician-instrument system, but it may constrain the outcomes of training, and trajectories through practice towards those outcomes.

Discussions between researchers on these projects led to the question at the start of this paper: 'what makes a good musical instrument?' For reasons discussed above, attempts at general answers based on isolating the instrument from the different systems it is embedded in (musicians, cultures, histories) quickly became unsatisfactory. This motivated us to develop a new proto-instrument in which the aim is not to achieve optimal design for passing a generalised evaluation, but rather to systematically probe the effects that different design choices may or may not have for different specificities. That is, what matters for different musicians and contexts.

5.2 Current Activities

The Vodhrán in its current form was developed to allow control over the specifications of a plate-based physical model synthesis, which is excited and damped by interaction with a two-dimensional pressure sensor embedded in a wooden box. (For technical details, see [21]). As an object, it affords tapping, hitting, pressing and other actions, while the physical model synthesis engine further defines the musical instrumental affordances. Moreover, the digital interface allows measurement of the musicians' interactions with the proto-instrument, and how these vary within individuals across time and contexts, and between different musicians.

Two separate empirical studies are currently underway with the Vodhrán, with different process and ecology specificities. Study 1 engages experienced musicians with different instrumental and performance backgrounds to explore versions of the proto-instrument which vary in the way that sound is controlled, specifically the mapping between pressure and damping of the modelled plate, and the mechano-acoustic complexity of the physical model synthesis (e.g. non-linear plate coupling vs a linear plate). Participants are asked to explore the different versions of the proto-instrument, and to compose and perform short pieces with them. Mixed Methods analyses (quantitative and qualitative data) are being carried out to understand the effects of different design configurations on the musicians' behaviours and experiences, how these may interact with the different musical activities they are asked to engage in, and any connections made with broader contextual, historical or stylistic concerns. Study 2 looks at the effects of different configurations for novices practicing a predefined exercise on the Vodhrán, akin to a musician-in-training working to pin down a fundamental instrumental technique. Any effects of variations on outcomes and performance changes over time will inform us about the de novo 'learnability' of the proto-instrument and how learners may try to navigate the structure of its affordances.

These two studies indicate the range of specificities that this developing instrument allows us to interrogate. No evaluation of 'better' or 'worse' configurations is being sought in either study. Rather we intend to learn which (if any) of the systematic variations to Vodhrán have meaningful effects for our participants in the musical situations we have contrived, and in what ways these might relate to the different specificities involved. Although the specificities we vary in these studies are more clearly focussed on the processes (affordances) instantiated by the proto-instrument, and broad differences on the musician side of the musician-instrument ecosystems, other aspects of these concepts may also be considered. In terms of socio-cultural ecologies, characteristics of the environments in which musicians in studies 1 and 2 might be anticipated to play the instrument are completely distinct. Experienced musicians might view the instrument in terms of how it would play in a performance setting with fellow musicians and discerning audiences, whereas for the novices in study 2, the potential

ecology of performance may be undefined or possibly pedagogic in character. In terms of the instrument as embedded in a temporally extended history of evolutionary processes, this is a central component of this project. Subsequent design iterations will reflect the history of decisions and lessons that precede and flow from these studies. In comparing outcomes of both studies, our approach can also show how these different contexts can inform and reshape each other and how these specificities can interact in wider ecologies of musical practice.

5.3 Future Trajectories

The current project is intended to inaugurate a longer term inter-disciplinary research programme at SARC, investigating design, performance, learning and evolution of new musical instruments from the conceptual framework outlined here. Ongoing and future research activities include (but are not limited to):

- Exploring boundaries of the instrument in terms of physical model parameters and breaking points for different musical activities (and possible new stable configurations which might emerge from these);
- Measuring longer term learning and changes with experience of playing the instrument among musicians with differing levels of pre-existing skill or expertise;
- Critical reflection by musicians preparing for and playing the instrument in different performance settings, and the relationships between the properties of the instrument and the characteristics of the musical contexts.

These goals are not fixed to the Vodhrán. Rather, it represents a first step of our group to apply and test some of the concepts discussed, which we hope will generate useful knowledge for stakeholders in the different communities of interest.

6. ACKNOWLEDGMENTS

This work was in part funded by an institutional Interdisciplinary Pump-Prime project grant from Queen's University Belfast.

7. REFERENCES

[1] E. Baggs and A. Chemero. The third sense of environment. In *Perception as Information Detection:* New York: Routledge, 5–20. 2019

[2] J. Barbosa, J. Malloch, M. Wanderley, and S. Huot. What does "'Evaluation'" mean for the NIME community? *Proc. NIME '15,* 156–161. 2015

[3] J. Bowers and P. Archer. Not hyper, not meta, not cyber but infra-instruments. *Proc. NIME '05*, 5–10. 2005

[4] M. Campbell, C. Greated, and A. Myers, *Musical Instruments*. Oxford University Press. 2004

[5] A. Chemero. *Radical Embodied Cognitive Science*. MIT Press. 2009

[6] S. Cottrell. *The Saxophone*. Yale University Press. 2013

[7] H. De Jaegher and E. Di Paolo. Participatory sense-making. *Phenom Cogn Sci,* 6, 485–507. 2007

[8] J. Dewey. 1896. The reflex arc concept in psychology. *Psychol Rev,* 3, 357–370. 1896

[9] J. Dyer, P. Stapleton, and M. Rodger. Advantages of melodic over rhythmic movement sonification in bimanual motor skill learning. *Exp brain res* 235, 3129–3140. 2017

[10] E. Gibson and A. Pick. *An Ecological Approach to Perceptual Learning and Development*. Oxford University Press. 2000

[11] J. Gibson. *The Senses Considered as Perceptual Systems*. Houghton Mifflin, Boston, MA. 1966

[12] J. Gibson, *The ecological approach to visual perception*. Houghton Mifflin, Boston, MA. 1979

[13] M. Gurevich and J. Treviño. Expression and Its Discontents: Toward an Ecology of Musical Creation. *Proc NIME '07,* 106-111. 2007

[14] A. Hazzard, C. Greenhalgh, M. Kallionpaa, S. Benford, A. Veinberg, Z. Kanga, and A. McPherson. Failing with Style: Designing for Aesthetic Failure in Interactive Performance. *Proc. CHI 2019.* 1–14. 2019

[15] A. Marquez-Borbon. Perceptual Learning and the Emergence of Performer-Instrument Interactions with Digital Music Systems. *Proc. A Body of Knowledge - Embodied Cognition and the Arts Conference*. 2016

[16] A. Marquez-Borbon and J. Avila. The Problem of DMI Adoption and Longevity: Envisioning a NIME Performance Pedagogy. *Proc. NIME '18.* 190-194. 2018

[17] A. McPherson, R. Jack, and G. Moro. Action-Sound Latency: Are Our Tools Fast Enough? *Proc. NIME 2016*

[18] F. Morreale and A. McPherson. Design for Longevity: Ongoing Use of Instruments from NIME 2010-14. *Proc. NIME '17*, 192-197. 2017

[19] S. O'Modhrain. A Framework for the Evaluation of Digital Musical Instruments. *Comp Music J,* 35, 28–42. 2011

[20] C. Palacio-Quintin. Eight Years of Practice on the Hyper-Flute: Technological and Musical Perspectives. *Proc. NIME '08,* 293-298. 2008

[21] L. Pardue, M. Ortiz, M. van Walstijn, P. Stapleton and M. Rodger. Vodhrán: collaborative design for evolving a physical model and interface into a proto-instrument. *Proc. NIME 2020*.

[22] A. Parkinson. Embodied Listening, Affordances and Performing with Computers. *Proc. ICMC '13,* 162–168. 2013

[23] E. Reed. An Outline of a Theory of Action Systems. *J Motor Behav 14*, 98–134. 1982

[24] E. Reed. The Intention to Use a Specific Affordance: A Conceptual Framework for Psychology. In *Development in Context*. Lawrence Erlbaum, Hillsdale, N.J. 1993

[25] E. Rietveld. Situated Normativity: The Normative Aspect of Embodied Cognition in Unreflective Action. *Mind, 117*, 973–1001. 2008

[26] E. Rietveld and J. Kiverstein. 2014. A Rich Landscape of Affordances. *Ecol Psychol, 26*, 325–352. 2014

[27] P. Stapleton and A. Melbye. VASPI Performance. *NIME 2017*

[28] P. Stapleton, M. van Walstijn, and S. Mehes. Co-Tuning Virtual-Acoustic Performance Ecosystems: observations on the development of skill and style in the study of musician-instrument relationships. *NIME '18.* 2018

[29] L. Suchman. *Plans and Situated Actions.* Cambridge University Press. 1987

[30] M. Turvey. Affordances and Prospective Control: An Outline of the Ontology. *Ecol Psychol,* 4, 173–187. 1992

[31] F. Varela, E. Rosch, and E. Thompson. *The Embodied Mind:* MIT Press. 1991

[32] J. Von Uexküll. A stroll through the worlds of animals and men: A picture book of invisible worlds. *Semiotica 89*, 319–391. 1992

[33] S. Waters, Performance Ecosystems: Ecological approaches to musical interaction. *Proc. EMS: Electroacoustic Music Studies Network '07*, 2007

[34] S.Waters. Touching at a Distance: Resistance, Tactility, Proxemics and the Development of a Hybrid Virtual/Physical Performance System. *Contemp Music Rev, 32*, 119–134. 2013

[35] Specificity. *Lexico*. Retrieved from https://www.lexico.com/en/definition/specificity