Improving the Instrumental Learning Experience through Complexity Management

Laurel S. Pardue
QMUL & AAU
static@alum.mit.edu

Andrew McPherson
Queen Mary University of London
a.mcpherson@qmul.ac.uk

Dan Overholt
Aarlborg University
dano@create.aau.dk

ABSTRACT

This position paper introduces the concept of complexity management in instrument design as a means to optimize the learning rewards cycle in an effort to maintain player motivation. Successful fluency and expertise on an instrument requires sustained practice. In the quest to enable exceptional levels of expression, instruments designed for virtuosic performance often have a high level of complexity, which can be overwhelming for a beginner, decreasing practice motivation. Here we explain complexity management, the idea of intentionally limiting instrument complexity on a temporary basis so that instrument difficulty is optimally matched to user skill and users always remain capable of focused learning and enjoy sufficient musical success to motivate continued practice. We discuss the relevance of Csikszentmihalyi's ideas about flow, along with concepts from traditional music learning, such as chunking and internalization, along with the importance of practice and enjoyment. We then propose our own concept of learning efficiency and the importance of controlling challenge. Finally, we introduce our own experiments into complexity management using the violin, an existing example of an instrument with high input complexity. We discuss the effects of simplifying intonation in order to make early musical success easier along with plans for further investigations.

1. INTRODUCTION

One of the main motivations for making novel digital music instruments (DMIs) is the idea of designing an expressive and interesting new instrument to enable new performance capabilities. However, despite the wide range of instrument outputs, expert performances with these instruments remain rare with expert performance by someone outside of the design process even rarer. We are interested in investigating the ephemerality of most new instruments and instrument augmentations, including well resourced projects [1].

A naive but regularly occurring focal point for perceived expressivity is that the more complex an instrument with more degrees of freedom, the more expressive and therefore more interesting and likely to be successful an instrument is; a common theme to improve a new DMI is to add additional new sensors to a tangible interface to make it more expressive. But there is cost to adding complexity through additional degrees of freedom, it makes the instrument more difficult and potentially distracts from the instrument's core strengths.

Balancing instrument expressivity versus difficulty is a constant challenge. To attract a potential player, ideally an instrument is easily rewarding. In contrast, virtuosic performance typically exploits a variety of complex inputs mastered through extensive practice. Digital instrument design tends to target either simplicity, or complexity. But if an instrument is too limited, it gets treated as a toy, while similarly, if it is too difficult, a learner gets despondent and quits. Either way motivation to practice the instrument drops and the expertise required to explore and utilize the instrument's richness is rarely achieved [2]. David Wessel refers to this balance as design for "low entry fee with no ceiling on virtuosity" [3].

We are interested in the idea of *complexity management*: the transient simplification of an eventually complex instrument in order to optimize the learning rewards cycle. Introduced in [4], complexity management is focused on how ideally basic musical success is achievable with low skills and, inline with an appropriate amount of effort, practice continuously yields musically interesting results. In theory, by adapting instrument behavior to sustain an optimal learning rewards cycle, a learner will be motivated to continue learning the instrument, improving the instrument's overall chance of uptake.

The primary purpose of this paper is to introduce the concept of complexity management as an idea within which to consider novel instrument learning, and thus potential success. A new DMI does not have the preexisting specialized repertoire, status, or learning methodology that aids learner motivation, thus, there is even more importance than with a traditional instrument that the learning process itself yields sufficient reward to sustain interest. This paper will discuss existing literature about motivation, pedagogical literature about instrument learning and development of expertise, before moving to discussions within the DMI community on perceived instrument potential and why we think it is necessary to include intentional consideration of the learning process. Finally, we will introduce our own fledgling experiments to validate the value of complexity management using a traditional but complex instrument, the violin.

2. MOTIVATION FOR PRACTICE

One definition for successful uptake of an instrument, at least within traditional musical contexts, is a handful of players voluntarily developing expertise on the instrument (i.e. beyond the scope of research participation). Developing expertise requires practice and practice requires sustained learning motivation. Thus, an almost equally important question to the success of a DMI becomes not just how does someone play a DMI but also how do they learn it.

Complexity management is inspired by computer game design and Csikszentmihalyi's ideas about flow [5, 6]. Investigating why people play, Csikszentmihalyi ascribes flow to activities that involve, absorb, and motivate people to seek them out; to be in flow is to do be optimally engaged.

> Flow is experienced when people perceive opportunities for action as being evenly matched by their capabilities. If, however, skills are greater than the opportunities for using them, boredom will follow. And finally, a person with great skills and few opportunities for applying them will pass from the state of boredom again into that of anxiety. [6, p.146]

Computer games, similar to non-professional musical study, are a play activity competing for attention and time. A well designed game targets optimal flow. It often starts with an experiential tutorial introducing how to execute basic tasks which a player must demonstrate they can accomplish. A well designed game then slowly increases demands on those tasks, or task difficulty, matching the challenge to the player skill level. Through this process, flow is maintained and players, including adults, commit to mastery of games. Complexity management is an attempt to apply similar optimal challenge principles to a musical instrument.

Another relevant aspects of games is how they provide a sense of accomplishment and with it, formal validation of skill progression, is designated through the winning levels or completion of specific game goals. In music, repertoire, the playing of which maybe rewarding in itself, acts similarly to validate skills progression. There is pleasure in both playing, and the achievement of having played the piece. When we talk about optimizing the learning progress, it is necessary not just to consider challenge and skill on their own, but also that the main reward on an instrument is the music itself. Working for a long time to figure out how to play an instrument, but not actually making music in the process is discouraging.

We will next delve into some of the theoretical pedagogy of instrument learning relevant to the discussion. Though the discussion focuses on traditional instruments there is a strong argument for it to remain relevant even for DMIs. This paper will subsequently return to literature about DMIs and the potential role for complexity management in improving the learning experience.

3. THE INSTRUMENTAL LEARNING PROCESS

In depth research on exactly how a person learns an instrument is quite limited, probably due in large part to the long time periods, easily 10 years [7], involved for someone to transition from a novice to an expert. However instrumental teachers will often spend years teaching a student and guiding them towards proficiency. Though pedagogcial writings are often informed by personal opinion and learning theories instead of scientific study, considering the scarcity of existing research, it would be overly limiting not to consider the opinions of established respected teachers and their extended accumulated experience.

Daniel Kohut, a wind teacher writing about effective teaching [8] says, "No two people are exactly the same physiologically or psychologically. Thus no two people function or learn in exactly the same way. Consequently, there is no single process or mode of function that is ideal for all of us to use beyond the general principles inherent in the natural learning process." Learning is an individual task and must be tailored to an individual's problem areas and style of learning. However, there are common principles that are universally shared.

3.1 Cognitive Load and Internalization

Learning must be a multi-stage process due to the high complexity and often large range of tasks required to master a given instrument. We are limited in how many things we can consciously handle at one time due to basic issues of conscious learning memory. Research by George Miller in the 1950s found that human short-term memory can deal with roughly "seven plus or minus two" discrete bits of information at any given time [9]. Subsequent research found that to convert those discrete bits into recallable long-term learning each discrete bit must be practised and repeated [10]. Because music places high demands on immediate recall, most musical skills must be learned internally so that only a few individual tasks demand space in our short-term memory.

Internalization is defined here as moving a behavior / gesture from being volitional to reflexive. Until the early 19th century, the most commonly accepted theory suggested that volition and reflex involved two completely separate brain functions. Modern explanations, however, encompass a more unified theory, which classifies all brain functionality as an interface between sensory input and motor output. In a simplistic view, our brains function as the mapping stage between our senses and our motor actions. [11] notes that "the reflex/voluntary distinction derived from the sensorimotor hypothesis of neuroscience is not absolute; all behaviors fall on a continuum from purely reflex to purely voluntary and none is purely one or the other." Such concerns are discussed in an article considering the use of technology to ride the reflex/volitional continuum in improvised musical performance [12].

3.1.1 Chunking

In a review of the cognitive neuroscience of music, Zatorre et al. [13] define *chunking* as "the re-organization or re-grouping of movement sequences into smaller subsequences during performance," and states, "chunking is thought to facilitate the smooth performance of complex movements and to improve motor memory." The implication of limited short-term memory and focus is that any large task achieved through the integration of many small tasks, must first start with internalizing the small tasks or *chunks*. The size of a learning chunk will depend on the sub-tasks required to achieve it and may be a combination of previously learned chunks or completely new ones.

Taking the hypothetical example of music reading, a foundational chunk is when the student must be able to identify that a dot (note) on the stave means a certain action. Playing the note requires the student to know how to execute the fingering action to achieve that note. It does not necessary assume the student understands the note name or pitch equivalent of the note. Another chunk for the student is to learn how the drawing of the dot impacts timing and when to move from a first dot to a second dot. For a single dot, we've already identified two tasks to learn: placement and timing.

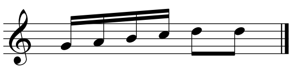

Figure 1. Simple chunkable pattern for beginners.

Having learned the basic meanings of the individual dots to a reasonable level, a student can then build upon that foundational understanding. For instance, taking an example from Kreitman, a popular author within Suzuki violin teaching, [14], rather than thinking of Figure 1 as four similar length short notes followed by two longer notes, the student can link the two to a single larger block: e.g. the mnemonic"bu-sy, bu-sy, stop, stop". The student can also recognize that the pitch pattern is four ascending notes, and with an understanding of key, either conscious or unconscious, can chunk the pitch pattern as four up then a repeated note.

The usefulness of planned chunking is the intentional focus on manageable learning to avoid cognitive overload. Guitar professor and author Joseph O'Connor's experience is, "Overload in either the number or complexity of the chunks results in difficulty and frustration. However naturally a student takes to the instrument at the beginning, it is worth resisting the temptation to add new topics." [15, p.52] Appropriate sizing and pacing of chunks is key to three things: successful learning, a sense of achievement, and continuing motivation. Managing task learning is not just for beginners but experts too. in an interview the author conducted with a local profession violin teacher and player, she stated, "One of my big complaints with teaching in the [higher] academies is teachers either give you all this technique to work on while studying complex pieces and it is too much, or they put you on scales for a year so you can focus on technique and you are miserable."

3.1.2 *Task Learning*

Having recognized there are a limited number of tasks requiring short-term memory that we can focus on at one time, we must ask how we internalise a single task so we can use it as a building block of a larger chunk. There are four stages of perceptual-motor learning [15] [1] :

1. unconscious incompetence
2. conscious incompetence
3. conscious competence
4. unconscious competence

In unconscious incompetence, a student is unaware they are not correctly performing a task. For instance, on the violin a completely new student may start by holding the violin up at the neck with the left hand. For classical technique, supporting with the left hand is incorrect because it is detrimental to longterm performance goals, but for a beginner it seems like an obvious way to support the violin [10]. Once the teacher has pointed out how to correctly support the violin through the chin and shoulder, the student transitions from unconscious incompetence to conscious incompetence. They know they are holding the violin incorrectly, but have not yet learned to hold it beyond understanding the verbal instruction. As the student practices and is reminded by the teacher to hold the violin correctly, the student moves to conscious competence; the student can correctly accomplish the given task when directing focus at it. After continued repeated practice, the task reaches unconscious competence. The student holds the violin correctly without thinking about it.

The main goal of teaching is to aid a student's learning by aiding or introducing conceptual understanding and motivating the student to complete the next two stages for internalizing a task. Unconscious incompetence requires either external intervention such as by a teacher, or instructional video, or extensive exploration for self-discovery, but the second two stages, conscious incompetence and conscious competence are where learning happens both with and without external assistance. Unconscious competence is the stage at which the learning task can be safely used as a task block that can be built upon for larger chunks [8, 15]. Having identified the need to separate learning targets into understandable tasks and the mental process through which a task must progress for proficiency, we must now consider how a student progresses a task from conscious incompetence to unconscious competence: practice.

3.2 Practice

Though the promotors of some DMIs may promise the DMI will enable 'instant musicianship' there is no reason to expect such a short cuts exists [16]. Theory, composition, and ensemble teachers, would almost certainly argue there is more to musicianship than just making pleasant sounds on an instrument. Further, our concepts of musicianship are based on context. In current society we are used to hearing highly skilled musicians which means we, as audience (and players) have expectations on what is a necessary level of expression and musical achievement. For comparison, it takes on average 3,400 hours to reach

[1] Though a widely accepted idea, there are a number of variations in the specific naming of these stages, for instance though both authors O'Connor, and Kohut [8, 15] discuss the same core concepts, both use different names.

ABRSM grade 8 [17] and the average music student has practiced for 10,000 hours by the time they graduate from conservatoire [7]. Learning rates are variable but largely due to effort. Shinichi Suzuki [18] says,

> Those who fail to practice sufficiently fail to acquire ability. Only the effort that is actually expended will bear results. There is no short-cut. If a five-minute-a-day person wants to accomplish what a three-hour-a-day person does [in three months], it will take him nine years.

A study of instrumental practice by Sloboda [17] supports Suzuki's observations. It found high standard deviation in achievement rates after a given number of years study, but also found that the raw number of hours required for instrumental progression was largely the same across both high-achieving and low-achieving individuals. Students who practiced more progressed faster.

However, there is a caveat to the idea that practice leads directly to progress; the practice must be correct. The classic phrase "practice makes perfect" is a misnomer: more accurately, "practice makes habit". Some of the biggest outliers in the Sloboda's study [17] were actually high-achieving students that took up to four times as many hours to complete a grade than average. The suggested cause of this is highly repetitive but ineffective practice blamed on inattention and repetition of error that must then be unlearned.

3.3 Motivation

O'Connor summarizes the average guitar student's attitude to practice,"It was repetitive, it isolated and concentrated on the difficult sections. It aimed at improvement and was not much fun. It was something you had to do in order to play well. It was almost a chore that had to be done to make progress towards a promised land where they would be able to 'play the guitar' " [15, p.114].

There are two types of motivation as referred to in pedagogical literature, which itself can be defined in this context as the reasons for acting or behaving productively towards practice and instrumental progress: internal and external [8]. External motivation might be a parent or teacher telling a student whereas internal motivation is the inherent motivation and drive of the learner, for instance a instrument designer trying to explore their newest instrument. Literature on instrument learning tends to be written from a pedagogical perspective of how best can an adult, be it parent or teacher, motivate a child to practice and develop good practice habits [10, 14, 18, 19].

Part of the challenge for DMIs is that they are typically being learned by adults. Not only is it argued that adults learn differently than children [20], but the environment in which a child learns is very different. One of the largest differences is that where previously there was external motivation from parents and a well defined structure of formal education possibly inclusive to the learning target, adults must typically rely on internal motivation and fit their studies into otherwise busy days. Adult learners are often self-directed [21, 22] and adults have different expectations on achievement and more awareness of a comparative lack of skills to those that learned young. Hence, it becomes necessary to look at improving intrinsic rewards including Csikszentmihalyi's ideas about flow, which Csikszentmihalyi describes at one point as "the kind of feeling after which one nostalgically says: "that was fun," or "that was enjoyable." [6, p136]"

4. DESIGNING FOR LEARNING

> ...most people, regardless of training, can differentiate between extremely poor and good performance... This can be, and often is, a negative factor in terms of motivation for continued practice after the first two or three months of study. Good students in particular become frustrated if the tonal results they achieve are poor. But once tone and intonation improve sufficiently, practice comes easier, because it is more fun when one sounds better. [8, p.30]

Kohut suggests the period between starting an instrument, when a student produces unsatisfactory and poor results, and the point when enjoyable sound can be made and "practice comes easier" as lasting only the first two or three months of study. But Kohut writes as a wind player and teacher. Violin pedagogy suggests the frustrating hump before being able to reasonably play basic tunes is closer to two years [10, 19, 23].

Having looked at some of the basic aspects of music learning theory, it is valuable to acknowledge that not all instruments have an equal learning process. Some instruments have fewer input parameters to master or can be easily and cleanly chunked while others, such as the violin, can not. Further, accepting that practice is essential for expertise, it is necessary to consider the effect of a particular instrument's learning process on practice motivation.

4.1 Learning Efficiency

In response to the challenge of designing new instruments Sergi Jordà presented the idea of instrument efficiency using traditional instruments for illustration. A traditional means for evaluating expected progress on an instrument is through a learning curve [24]. Intuitively, the learning curve maps the expected relationship between cumulative applied effort and demonstrated musical skill within the context of that instrument. Conventionally, a learning curve does not capture the inherent fluency of the instrument or whether it yields an interesting virtuosic output.

Jordà [24] attempted to capture some of what makes a toy versus a virtuosic instrument by looking at instrumental progress in terms of efficiency, a combination of the freedom the performer has to shape music and the potential complexity of the music they can produce, versus the complexity of input control. He calls this *music instrument efficiency* described by the pseudo-mathematical equation:

$$\textit{Music Instrument Efficiency} = \frac{\textit{Music Output Complexity} \times \textit{Perf. Freedom}}{\textit{Control Input Complexity}} \quad (1)$$

Though output complexity vs. input complexity loosely represent a more conventional idea of efficiency, music instrument efficiency includes performer freedom as a variable. Elaborating why it is included, Jordà gives the example of a CD player. Hitting play triggers a complex musical output with a simple low complexity input, yet no one would consider a CD player an interesting instrument as there is no effective performance freedom. Music output complexity reflects the variation and range of outcomes available to the player, and control input complexity reflects the degrees of freedom in input and gesture that produces those outcomes. This concept is can also be seen as a balance of power between musician and machine, as described in [25].

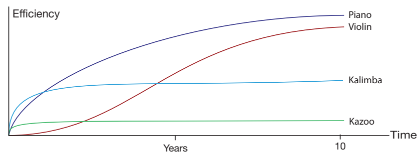

Figure 2. Sergei Jordà's learning curve based on music instrument efficiency [26].

Music instrument efficiency, as illustrated in Figure 2, lets us compare expressive virtuosic potential between instruments with some instruments having inherently more potential than others. According to Jordà, efficiency changes with experience and practice. In Figure 2, we see the violin has very low starting efficiency as it has high input complexity, but inability to control inputs means low performance freedom and simple output. A kalimba is much more efficient with low experience thanks in part to reasonably simple starting controls, but the efficiency curve flattens due to limited output complexity and the instrument never reaches high efficiency. The guitar is capable of reduced input complexity and thus has reasonable early instrument efficiency. Virtuosity at the guitar results in arguably less performance freedom than the violin, but more output complexity thanks to its polyphonic nature giving it a theoretical music instrument efficiency curve somewhere between the violin and the kalimba [2].

4.2 Reward for Practice

A significant limitation in Jordà's idea of defining instrument quality and learning curves through musical instrument efficiency is that it fails to incorporate the learning experience. Figure 2 implies learning through time, but his discussion of instrument efficiency is limited to the the mechanics of the instrument ignoring the learner's enjoyment, a necessary requirement for sustained playing motivation. It ignores the role repertoire and musical outcome play in influencing the reward cycle. As will see with the violin (Section 5.3), it also ignores the interaction between input capabilities and the effects that can have on learnability.

[2] We are not arguing that one instrument is necessarily harder to play virtuosically than another, only that some instruments are initially harder. Nor are we arguing that one instrument is in any way better or more beautiful than another.

Without these additional factors, the idea of musical instrument efficiency is useful at enabling a best guess of an instrument's hypothetical end potential, but is ill equipped to illuminate how a player gets from beginner to virtuoso. We find it more useful to explicitly consider the amount of practice and work required to achieve musical success from beginning to end.

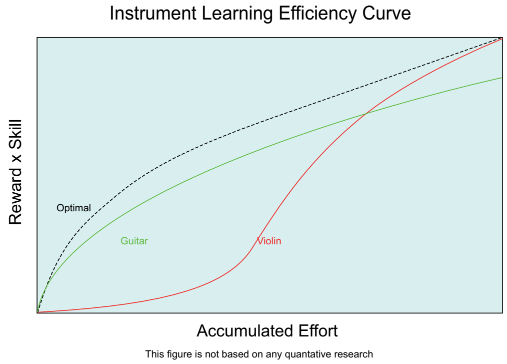

Figure 3. Sample expected learning and reward curves for the violin, guitar, and an ideal.

Figure 3 is illustrative of possible relationships between effort, and skill and reward for the violin, guitar, and an ideal instrument. Similar to Jordà's idea of music instrument efficiency [26], rather than the traditional learning curve of effort versus skill, we use a *learning efficiency* curve based on instrumental skill, which is related to music instrument efficiency, but also adds musical reward, the production of enjoyable musical output. Although improved skill is a motivation in itself, we believe that in the vast majority of cases, enjoyable musical outcome while developing skills is necessary to keep the performer interested. Including reward along with skill takes into account whether the results of learned output controls are sufficient to be musically satisfying.

5. MAKING AN INSTRUMENT INHERENTLY EASIER (OR HARDER)

Considering the pedagogical fundamentals of chunking and internalization, we argue that successful learning of a complex instrument relies on the ability to repeatedly chunk, and internalize playing technique. The starting point must be simple, with technique able to gradually build, but always retaining a useful musical output. To explain the usefulness of complexity management, let us compare the early learning experience on the violin, an instrument with poor learning efficiency, with the piano, an instrument with good learning efficiency, and then discuss how to one might artificially use complexity management to improve the violin's learning efficiency to be more on par with the piano. We interviewed a professional guitarist and composer about his experiences attempting to learn both viola (requiring similar technique to a violin) and piano (at least one hour of practice a day for minimum six months) and reference his experiences.

5.1 Simplifying Piano vs. Violin

The piano has high learning efficiency because it is easy to simplify while still making music. The composer stated, with the piano, "There is really no impediment to making a sound. You press a button and it makes a beautiful tone *every single time*." When learning piano, simple monophonic tunes can easily be learned by selecting the correct keys in order; first with one hand, and then the other. Complexity can then be increased by combining both hands, or introducing polyphony to one hand, and then the other. Once a reasonable amount of proficiency has been reached with each hand, complexity once again can be increased adding foot pedals. Along every one of these steps, each introducing a new level of complexity, there remains music reward.

On the violin (and viola), unlike with the piano, neither pitch nor tone are given. There is limited haptic feedback for finding the correct pitch, and even what the note sounds like has to be learned [19]. Then there is the bow. Successful use of the bow requires control of seven independent parameters [27], with the basic control of one of the main parameters taking 700 hours to learn on its own [23]. On top of that, violin posture is awkward. The problem on the violin is that none of these complex parameters- how to hold the violin, finger placement on the fingerboard, and bow control- can be easily separated from one another while still yielding interesting music. Our composer stated, "there was absolutely nothing easy about learning the viola. At any given moment, there are, like, seven to twelve things one has to keep in mind..." and the result was "[more often than not] terrible, screeching non-pitches". It is not surprising to learn that after first trying to learn viola for 8 months, practicing an hour every day, the composer quit, tried piano, and has continued with enthusiastic practice for the past three years stating, "it's the most elegant instrument I've encountered."

5.2 Applying Complexity management to a Violin (or Viola)

The problem on the violin (and viola) is that it is not possible to simplify and separate the different skills involved in the same way as can be done through repertoire on the piano. Meanwhile musical reward is extensively delayed while technical skills are being accumulated, and there are a lot that need to be accumulated. DMIs may not come with graded standard repertoire, but at the same time, nor do the they face the same inherent limitations on how they can be simplified.

If we used digital technology to redesign the violin we could potentially break the troublesome dependencies an allow beautiful results from the beginning, while slowly adding in the complexity eventually required. For instance, if we allowed any bowing, good or bad, to produce an even tone and added virtual frets on the violin, we could have a student focus on basic posture while still pleasantly accomplishing simple songs. Once posture was proficient, we could start letting bow skew (crooked bowing) impact tone quality. The number of new tasks to focus on remains low and approachable and musical output remains achievable. Once a player is proficient with bow skew, we could remove the virtual frets moving the focus of learning to intonation and so on. At each stage, we are introducing one technique, gradually restoring the complexity of the traditional instrument but always retaining musical reward.

One of the rules of instrument design is that large amounts of input control do not necessarily increase expressivity [25, 28]. Referring to 3D motion capture, Bevilacqua [29] states, "A general problem with using a motion capture system as a controller for musical processes is that at 900 events/second ($\sim$ 30 points at 30 Hz), there are simply far too many to translate directly into a coherent musical process." 30 control points for each moment in time does indeed seem like a lot, but that is only if we expect a learner to master all 30 points simultaneously and treat each point as a separate system. If we can simplify through complexity management and the application of traditional learning methods of chunking, repetition and internalization, with practice, 30 points may turn out both naturally connected and easily manageable.

5.2.1 Challenges

Although pacing of difficulty and complexity is considered a major design aspect in computer gaming, applying the concept through instrument design whose behaviour changes over time has not been well received amongst DMI designers. In his list of key DMI design rules, Perry Cook's second rule is "Smart instruments are often not smart." Cook [30] states, "learning from [a musician's] play and modifying its behavior often does not make any sense at all, and can be frustrating, paralyzing, or offensive." However, performable systems have been created that do not rely on pre-determined mappings and may indeed be "smart". Dave Merrill created *Flexigesture*, a tool to explore how different users might arrive at and prefer different mappings for a single interface [31].

We recognize that intentionally simplifying a novel instrument may lead to different playing styles than might exist if not simplified, or additions of new complexity may be disruptive to already learned technique, however we suggest that for instruments targeting longevity, the inclusion of sound pedagogical learning principles and complexity management into the design may assist uptake.

5.3 Studying Complexity Management with the Violin

Focusing on longterm practice motivation means any in depth study of complexity management would be similarly longterm. The long term nature and the need to keep participants committed for an extended duration necessitates careful design of an appropriate test instrument, test simplifications, and preliminary studies to validate basic hypotheses such as 'beginners will enjoy this simplification.' Important initial questions in support of the primary question, can we improve learning efficiency through the management of instrument complexity, include how do we successfully alter complexity in a non-disruptive way, how fast do you add complexity, and would reduction of complexity habituate poor technique?

We have begun initial investigations not on a novel instrument, but with an augmented violin. We choose to investigate complexity management using a traditional instrument as with a new DMI there is no performance history, tradition of success (or failure), or repertoire. An augmented violin is a good candidate for complexity management for the challenges to violin learning previously described. Additionally, violin technique is well established so we can judge outcomes in relation to normal methods and there is a substantial pool of people who want to learn violin. Provided skills developed playing our augmented violin transfer to general violin playing, the likelihood of attracting and sustaining a test group is much higher than with a novel interface.

We have already designed and tested an augmented violin system capable of providing real-time pitch correction and performing basic bow tracking [32] for use in studying complexity management. We initially identified pitch for simplification with the idea that if we corrected pitch, we could both qualitatively improve the resulting audio and through that make musical success easier. Simultaneously it might potentially relax some of the mental processes normally devoted to focusing on intonation enabling improved musical results while working on bow techniques.

One potential drawback is that if we remove heard intonation error a player will be unable to self-identify error. Learning both what correct intonation sounds like and how to reproduce it is a core part of learning intonation. Playing in-tune is a rapid repetitive process of detecting intonation error and correcting it [4, 14]. If a beginner can not hear intonation error, they will not learn to correct it violating our goal of skills transference.

Using headphones to block acoustically produced sound and replacing it with pitch corrected audio in real-time, we studied the effects on both fully and partially correcting pitch with a range of 20 violinists, from young beginners, to adult professionals in two studies [4]. We wanted to investigate the effects on actual performance, and also whether simplifying pitch through pitch correction actually improved musical enjoyment, potentially improving the reward cycle.

Results suggested statistically significant differences between uncorrected as-played intonation in all three cases, playing with no correction, partial correction, and full correction. Removing all intonation error negatively impacts intonation, but removing only partial error is clearly enough to restore some level of error correction by the player while the musical outcome is still heard as fairly in-tune. The improvement seen with partial correction suggests it is possible for us to artificially improve heard intonation while not sacrificing the ability to correct error. Interestingly, though professionals showed strong distaste to being pitch corrected due to loss of control, preference was strongly correlated with experience. In contrast to experts, beginners, including children and adults who would be our primary target audience for intonation simplification, typically reacted positively expressing that it allowed them to relax while playing and hear themselves play really well (even if in reality, they did not).

We considered results from our pilot studies very encouraging for continuing explorations into applying complexity management to the violin. Our next stages are to build more robust and easy-to-use systems that students can take home themselves for further longitudinal studies, and also design an actively actuated acoustic violin to eliminate the need for headphones.

6. DISCUSSION

Though we can not yet offer any conclusive results on the efficacy of complexity management's ability to improve the reward cycle, we encourage DMI designers to consider how to target flow and best improve user experience dependent on user skill. We have argued why it is necessary to consider how to sustain practice motivation and enable learning to succeed.

It is worth remembering instrument play evolves. Violin as played today is something we know to be an expressive instrument, but is an inherently complex instrument that would probably flounder if it was introduced as a new instrument today. The change in what is considered achievable and with that the level of complexity demanded for violin performance has been consistently evolving. Violin would have started in folk music, where formal study would have been rare and technique demands typically low. Gradually through the years the technical demands placed on the player have gradually increased and what used to be virtuosic is now standard repertoire. We may expect the same with any successful DMI.

Still, just as in traditional learning, if we fail to consider practice and practice motivation, we can never expect a student to successfully learn control of the 30 points of motion capture data Bevilacqua [29] considers too difficult. Instrument complexity is very often talked about in DMI communities [26, 33], but strategies for addressing complexity stop at instrument build rather than learning and repertoire. It is in learning where DMIs can have an inherent advantage over traditional instruments. In traditional instrument study, practice and learning are where strategies for dealing with complexity start. With augmented instruments and DMIs, we have the opportunity to consider complexity at all stages.

Acknowledgments

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