DEPARTMENT OF COMPUTER SCIENCE

Evolutionary Musical Interactions in Virtual Reality

An Exploratory Study

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A dissertation submitted to the University of Bristol in accordance with the requirements of the degree of Master of Engineering in the Faculty of Engineering.

Friday 4th May, 2018

Declaration

This dissertation is submitted to the University of Bristol in accordance with the requirements of the degree of MEng in the Faculty of Engineering. It has not been submitted for any other degree or diploma of any examining body. Except where specifically acknowledged, it is all the work of the Author.

Dhruv Chauhan, Friday 4th May, 2018

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Supporting Technologies

- I used a HTC Vive Virtual Reality Headset, with 2 Controllers.
- I used Unity to develop the front end of the VR experience.
- I used VTRK, a VR Toolkit for developing controls in VR with Unity.
- I used Google Poly Toolkit for Unity, a resource for 3D Poly Models.
- I used Pure Data, an open source visual programming language to develop a subtractive synthesizer which forms the musical back-end of the project, found at https://puredata.info/.
- I used LibPD (an embeddable audio synthesis library version of Pure Data).
- I used C# as the back-end of the project, with Unity.
- I used an iPhone as a voice recorder to capture the audio from the interviews.
- I used the webapp 'transcribe' to aid with the transcription of the recorded audio.
- I used Nvivo to code the interviews and perform thematic analysis.

Notation and Acronyms

A/B Test	:	Controlled experiment with two variants.
ADSR Envelope	:	Attack-Decay-Sustain-Release Envelope, parameters that specify the contours of an envelope, commonly used to modulate sound.
DAW	:	Digital Audio Workstation
GAs	:	Genetic Algorithms
HCI	:	Human-Computer Interaction
LFO	:	Low Frequency Oscillator
NIME	:	New Interfaces for Musical Expression
PD	:	Pure Data
QDA	:	Qualitative Data Analysis
RtD	:	Research Through Design
SSIs	:	Semi-structured Interviews
SSQSs	:	Semi-structured Qualitative Studies
UI	:	User Interface
VCA	:	Voltage Controlled Amplifier
VCF	:	Voltage Controlled Filter
VCO	:	Voltage Controlled Oscillator
VR	:	Virtual Reality
VRMIs	:	Virtual Reality Musical Instruments

Acknowledgements

I'd like to give thanks and express my gratitude towards all those who helped with my project. Particularly Pete Bennett, who helped to shape my original idea, and offered help throughout the process. I'd also like to thank Beth and Richard, the Teaching Technologists, for providing the VR hardware and space, without which the experiment could not have been done. Also, Aisling O'Kane for providing resources and guidance surrounding qualitative research. In addition, the participants in my study, and all those close to me who helped in reading and shaping the report - thank you.

Executive Summary

In this research study, I introduce and analyse a new Virtual Reality musical interaction system that uses a user-guided evolutionary algorithm to personalise musical instruments to users' individual preferences. The system is designed towards being an 'endlessly entertaining' experience through the potentially infinite number of sounds that can be produced. The hypothesis of the paper was to see if using this trio of technologies augmented a user's immersion levels. I explore surrounding literature, and pull from existing evaluation methodologies to guide and test the system. In addition to this, the system was designed to inform novel research into this unexplored area. After creating this system, a qualitative user study was performed — where users were asked to 'think-aloud' whilst interacting with the system, followed by a Semi-structured Interview. Thematic analysis was conducted upon the data corpus, in which 3 main themes, and 2 additional areas, were found: control, comparison to the real world, immersion, general usability and limitations. In the study, users pointed towards several improvements that would help increase their levels of immersion, such as increased levels of control through augmented visual feedback. It was found overall that this combination of technologies did improve immersion levels, proving the hypothesis to be true.

Chapter 1

Introduction

1.1 Overview

The overall aim of this project is to create a novel musical experience that is an intersection of three existing fields: Virtual Reality, Evolutionary Algorithms and Musical Interaction. Although plenty of research already exists into each field, and even between pairs of each, very limited research has been done with all three. Virtual reality technology still offers many open avenues for users with novel interactions and experiences. The music domain is particularly of interest as creating, or interacting with, music is a challenging and expressive activity [50]. The open-endedness and subjectivity of the music domain also lends itself to evolutionary algorithms, particularly where a user-centric method is used. This project prototypes an interactive virtual musical system in which a user explores possible musical interactions, and based on their preferences, informs an evolutionary algorithm. I aim to show that the union of these 3 areas increases the overall engagement, and therefore period of time spent, with the experience, and to use the resulting analysis to inform further research.

1.2 Motivation

Music has always had an effect on technological innovation [40], but novel technologies have also led to new musical innovation. The creation of novel musical interfaces helps to inform a new dialogue with music. When the modern piano was created, it gave birth too much of the classical music known today. In the 1950s, the new wave of synthesiser technologies gave rise to many new kinds of music, and in the 1990s, the rise of personal computation and cheap Digital Audio Workstations (DAWs) again led to much innovation.

As a response to this, many communities have sprung up in order to try to understand how to create optimal mappings between human behaviour and musical expression. The New Interfaces for Musical Expression (NIME) conference explores the use of many novel interfaces and technologies, and have attempted to create and explore guidelines to inform good design, and quantify evaluation of interfaces.

Virtual reality offers much potential for new musical expression, surrounding research of which is either quite dated or sparse. Modern technologies have meant that rapid prototyping and testing of virtual environments is very possible. Considering the lack of research or methodologies in this area, using a Research through Design approach can help foster new research in this area.

Given the vast space of technologies and interfaces that already exists, personalisation, or user-centric design is gaining popularity [39]. User-centric design means that users can themselves influence the final design of a product, or even create a process of continuous adaptation of interfaces. Evolutionary and Genetic Algorithms offer a potential avenue to explore this in.

In many areas of HCI research, there aren't clear quantitative measures that can be used as a means of analysis and evaluation. Qualitative research, including thematic analysis methods, gives other ways of conducting research in a more open-ended format [45].

1.3 Objectives

Pulling these fields together, I aim to create a completely novel system that incorporates Virtual Reality and Evolutionary Algorithms as a means to create a musical interface, which keeps users engaged and fascinated. As this interwoven field has almost no direct research upon it, I also aim to use this prototype experience to inform further research, through an iterative design process with qualitative data collection and analysis. Specifically, the high-level objectives are:

- Research and survey existing literature around Virtual Reality, Evolutionary and Genetic Algorithms, and Musical Interfaces and Interactions.
- Design, implement and prototype a novel virtual musical interface experience that uses Evolutionary Algorithms to inform the process.
- Plan and conduct a set of Semi-structured Qualitative studies where users interact with the experience. After this apply analysis methods to the data corpus to draw out key themes.
- Discuss and evaluate the key themes, outlining how the process undertaken may be used to inform future research.

1.4 Chapter Summary

- Chapter 1: An introduction to the project, its motivation, and an overview of the objectives.
- Chapter 2: The contextual background surrounding the project is presented and explored, weaving between Virtual Reality, Musical Interfaces and Instruments, and Evolutionary Algorithms.
- Chapter 3: The process of creating the system is detailed, along with its technical specifications, and justifications for the route taken.
- Chapter 4: The design and procedure for the user study is shown. The demographic data of the participants is given, and the literature surrounding Qualitative Studies is explored.
- Chapter 5: The results and themes from the study are explored in the context of the data corpus.
- Chapter 6: The themes that arose are discussed and evaluated in greater detail.
- Chapter 7: The conclusions from the study are given, along with an evaluation of the overall process. Potential future work is also presented.

Chapter 2

Contextual Background

2.1 Musical Instruments

A commonly adopted definition of a musical instrument is described by Hornbostel, "... for the purposes of research everything must count as a musical instrument with which sound can be produced intentionally." [28]. This rather loose definition of what classifies an instrument is explored by Kvifte as an interaction loop between user, instrument and interaction [31]. In this project I distinguish between VMIs (Virtual Musical Instruments), which work as "software simulations or extensions of existing musical instruments", and VRMIs (Virtual Reality Musical Instruments), which also includes a "simulated virtual component", viewed via HMD, as shown by Serafin et al. [42]. To this end, my usage of *instrument* does not refer to a musical instrument understood in the conventional sense, but rather as a virtual, interactable object, which when interacted with by a user, manipulates sound intentionally.

2.2 Creating New Musical Interfaces

The creation of new musical interfaces in recent years has been a factor in the expanding number of musical forms [40]. Music serves as the perfect mid-point of technology and musical expression, due to its open-endedness. Research around, and analysis of these new musical interfaces is essential. Some of these interfaces challenge what is expected from musical interfaces, and in doing so have the potential to revolutionise the dialogue between humans and music.

Wanderley et al. [51] describe 4 main categories of instrument controllers: instrument-like controllers, instrument-inspired controllers, extended instruments, and alternate controllers. The first two take influence of varying degrees from existing acoustic instrument control interfaces, and the third uses technology to augment or enhance an existing acoustic instrument. The final control interfaces are not tied to those of any existing instruments. Virtual reality provides a new method of potential control for instrument controllers, with an open-endedness to how the controllers may be used. Hypothetical instrument control mechanisms can be quickly and relatively painlessly trialled, opening the door to exciting new research.

2.2.1 Musical Interfaces Evaluation Criteria

Poupyrev et al. [40] explore some key criteria for evaluating new musical interfaces, falling into the following areas:

- usability and comprehensibility
- expressiveness
- sensitivity and sophistication
- aesthetics
- hedonics (pleasure of use)

Through this project, I use these evaluation criteria to inform my design.

Blaine [8] explores the effect of novel musical interfaces upon interactive entertainment, particularly for the gaming industry. She concludes that depth of input and control, along with novelty are key factors in influencing which interfaces are successful. One such novel technology that may be capitalised upon to this end is Virtual Reality.

2.3 Virtual Reality

Milgram [36] describes the range of possible levels of virtualities in the Reality-Virtuality continuum, seen in Figure 2.1, ranging from the completely real, 'reality', to the completely virtual, and representing all possible in-between mixtures of reality and virtuality in this continuum. For the purposes of this project, a completely virtual environment is used, and therefore this falls on the completely-virtual end of the continuum. However, as the controllers used inside the VR experience represent physical controllers (they are not augmented, but rather virtual representations of a physical object), it could be said that the experience falls slightly short of being on the end of the spectrum.

2.3.1 Telepresence and Influence Factors

The definition of VR as a new medium, consisting of a 'locus of technology' is explored by Steuer [46], and is ultimately dismissed as being inadequate for makers of software for VR, as a definition based purely on the technology does not give any "insights to the processes or effects of the system". He goes on to elaborate on a new definition, involving the notion of telepresence: defined as "the notion of being elsewhere" [3]. The final definition he proposes is a "simulated environment in which a perceiver experiences telepresence". As the diagram shows, Steuer considers the various factors that help to create a telepresence, falling under the umbrellas of 'vividness' and 'interactivity'.

In my project, the 'vividness' of the experience comes from the 'breadth' of incorporating visuals (the Unity scene), and the audio from the sound engine. The 'depth' relates to how detailed each of the sensory fields are.

The 'interactivity' of the experience is defined by Steuer as "the extent to which users can participate in modifying the form and content of a mediated environment in real time". He considers 'speed', i.e. how quickly the environment may be modified, 'range', or the number of possible interactions. Finally, the 'mapping', which refers to the ability of the system to map the controls onto changes in the environment in a "natural" and "predictable" manner.

I take Steuer's considerations in mind when designing my system, and therefore I aim to maximise the telepresence of the users, and note any responses in this area as of potential interest. In particular the considerations of 'vividness', or the 'depth' and 'breadth' of sensory information that my resulting system gives, and the 'interactivity', and the sub-variables that influence it. I consider the effects of both of these factors on how engaged, or immersed a user may be.

2.3.2 Immersion, Engagement and Presence in VR

Following on from Steuer's definition of VR in the context of telepresence, Slater et al. [44] look at immersion as the synchronicity between bodily feedback, and resulting feedback from the VR medium — for example, a physical turn of the head to the left ought to correspond to the movement of the field of view inside the display to the left. The coherency between these two interactions helps to produce immersion. They differentiate between the notions of immersion and presence, as presence often requires a 'self-representation', or a virtual body. Dede [19] defines immersion as "the subjective impression that one is participating in a comprehensive, realistic experience", and again refers to increased use of "design strategies that combine actional (actions infeasible, or an extension of real world actions), symbolic (content of experience), and sensory factors", which all cause a greater "suspense of disbelief", and therefore a greater level of immersion.

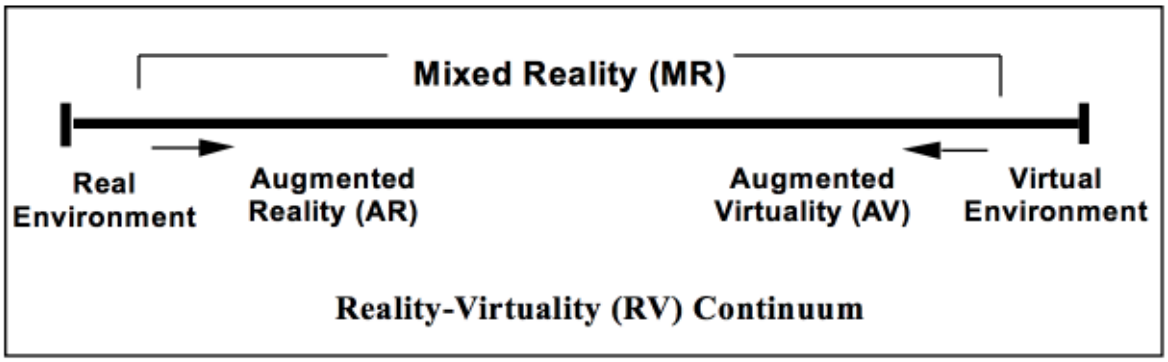

Figure 2.1: A diagram representing a simplified version of the Reality-Virtuality Continuum [36].

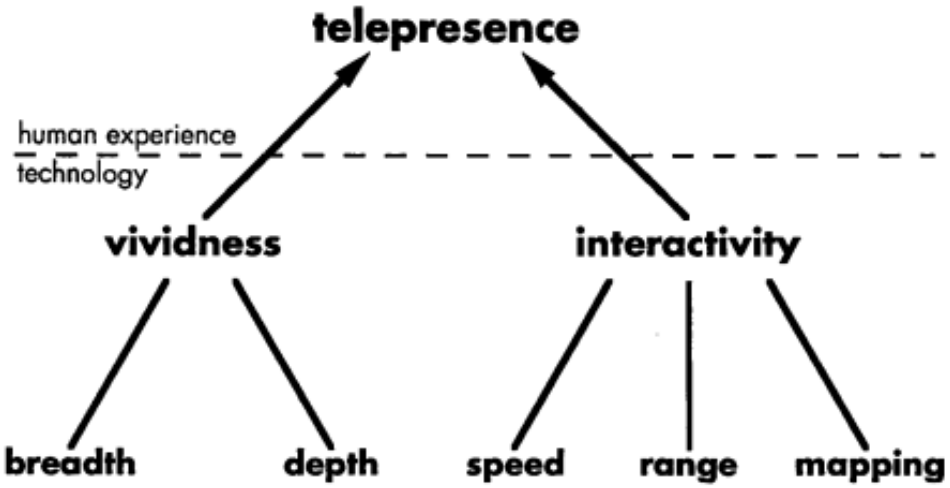

Figure 2.2: Showing the relationship between technological variables influencing telepresence [46].

Although in informal contexts "immersion" and "engagement" are used synonymously, McMahan [35] draws from Janet Murray's [37] definition of immersion as a metaphor: "*derived from the physical experience of being in water. We seek the same feeling . . . the sensation of being surrounded by a completely other reality . . . that takes over all of our attention.*" She also explores the notion of "deep-play" as a measure of engagement, which is described as "to be engaged to a level of near-obsessiveness". Clearly, exact definitions for both are slippery, and therefore for the purposes of this experiment I assume that immersion and engagement, when stated by informal users of the experiment, are pointing towards the same notion of 'feeling inside' the experience. As presence is not a factor that is being explored in this experiment, I do not aim to explore it, unless it arises as a specific theme. One of the factors I do explore is whether Evolutionary Algorithms have an influence on the level of immersion from a musical interface experience.

2.4 Virtual Reality Musical Instruments

Jaron Lanier [42] prototyped an 'abstract virtual world' and 3 VR musical instruments in 1987: the 'Rhythm Gimbal' a gyroscopic choral harmony generator; 'CyberXylo', a mallet instrument that maintains angular momentum; and the 'Cybersax' an ergonomically-dynamic instrument [32] — all 3 are designed to harmonise and play together. These instruments highlight some things that are possible with Virtual Reality technology. Since 1987, consumer technology has advanced vastly, and in the time, there have been other explorations between virtual reality and musical instruments.

VRMI	DP1: Feedback and mapping	DP2: Latency	DP3: Cyber sickness	DP4: Do not copy tech.	DP5: Interaction Natural/Magical	DP6: Ergonomy	DP7: Sense of presence	DP8: Body represent	DP9: Social Experience
Rhythm Gimbal CyberXylo CyberSax	AV in tandem Generic audio Virtual world	N/A	N/A	Leverage by new techniques	More magical	N/A	N/A	Abstract Hand	Audience Considered
Virtual Membrane Virtual Xylophone Virtual Air Guitar Gestural FM Synth	AV in tandem Physical models (Generic Audio)	ca. 60 ms ca. 60 ms ca. 60 ms Not noticeable	N/A	Copy Extension Extension Extension	More natural	N/A	N/A	N/A	N/A
Virtual Flute Virtual Drum	AV in tandem Physical models	Mentioned, but not evaluated	N/A	Copy	Natural	N/A	N/A	N/A	N/A

Figure 2.3: Historical VRMIs evaluated according to the 9 design principles outlined by Serafin et al. [42].

Serafin et al. [42] propose a set of design principles for evaluating Virtual Reality Musical Instruments, which are as follows:

- Design sound, visual, touch and proprioception in tandem, and consider the mappings between these modalities.
- Reduce latency.
- Prevent or limit cyber-sickness.
- Do not copy but leverage expert techniques.
- Consider both natural and magical interactions.
- Consider the ergonomics of the display.
- Create a sense of presence.
- Consider the representation of player's body.
- Make the experience social.

I will later use these design principles to evaluate my design. The evaluation of some instruments described below is seen in Figure 2.3.

Mäki-Petola et al. [34] have also created a range of instruments, such as the virtual xylophone, virtual air guitar, and gestural FM synth. Particularly interesting is that they have focused on creating VRMIs that take full advantage of VR's potential to create instruments not constrained to the physical world rules, such as live dimension-manipulation of instruments.

Lanier's [32] instruments are based on generic audio synthesizers, however the others incorporate physical audio modelling [42]. Physical modelling synthesis refers to synthesis where the sound is generated through a mathematical model, used to simulate a sound source, such as a musical instrument [41]. The virtual instruments described by Mäki-Petola all use this method of synthesis, except for the gestural FM synth. Incorporating physical modelling and virtual reality is a very interesting idea, however slightly beyond the scope of this project. The idea of incorporating two, usually distinct, fields is exciting, leading me to explore what other unconventional technology, methodology, or algorithm could be used.

2.5 Evolutionary & Genetic Algorithms

Genetic and Evolutionary Algorithms, as described by John Holland [27], are an optimisation method, taking inspiration from biological processes and natural selection. They give a way of navigating a problem space, and can often come up with solutions that traditional optimisation methods cannot. Calculus based methods, for example, often converge on local solutions as they explore the neighbourhood of the problem [39]. Using the fundamental ideas of survival and inheritance, they are stochastic and non-linear.

The process of an evolutionary algorithm involves creating a genetic representation of the system, constructing a population, choosing a fitness function, and a selection method [22]. A specific kind of crossover and mutation are selected, and a new generation is yielded. This is repeated across generations

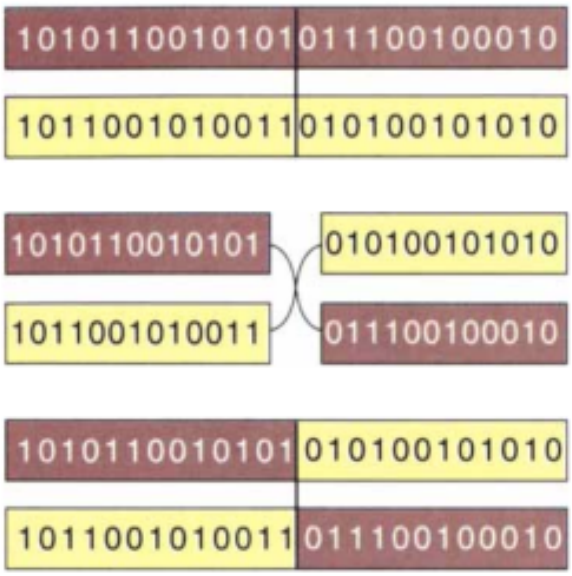

Figure 2.4: Genetic Crossover Algorithm Visualisation [27].

until certain criteria are met.

The crossover algorithm, seen in Figure 2.4 is key to the genetic mechanism. This algorithm involves two, or more 'parents'. The genome is split into parts, and then is recombined in different ways to produce offspring. Common types of crossover algorithm include 'one-point', where a specific crossing point is chosen, and 'uniform', where the genome is evenly split.

Another essential mechanism is mutation, where small, random variations are introduced into genetic material, thus allowing exploration into new, previously unexplored variations on previous solutions. The fitness function of a genetic algorithm evaluates the 'performance' of a specific instance, either through a specific, quantified function, or through a subjective, user-based fitness. In traditional usages of genetic algorithms, the termination often involves converging on a maximum fitness value, or when the fitness stops improving after several generations. This however can be less clear in more open-ended domains, such as with music.

2.6 GAs in the Context of Music

Clearly, unlike some other areas, the music domain does not offer an immediately clear fitness function, however some existing work shows that they may have an application. Biles explores the possibility of applying genetic algorithms to generation of jazz solos [7], whereby a live user gives subjective feedback which is converted into a fitness function. Continuing from this, Wiggins et al. [52] applies evolutionary methods in computer music composition — instead of using a human guided fitness function, they attempt to use a GA based on musical domain-specific knowledge to model human musical preferences. However, they conclude that this is unsuitable, as GAs do not accurately model human preferences. From this work, I had an inclination that perhaps involving the user in the GA would be the best way to proceed.

The work done by Keijzer et al. explores Interactive Evolutionary Algorithms (IEAs) [29], which are named due to their need for a user in the fitness function. Their work is done in the context of learning subjective fitness functions to create 'pleasing' drum patterns. Using a subjective fitness function with evolutionary algorithms, explored in the above papers, as a way for a user to navigate a space of sounds yielded patterns that suited the user more than without a user input. However, personal preference of music means that what a user deems a successful result may vary vastly depending on the user and their background.

Poirson et al. [39] explore the role of user-centered design in making instruments, and how this can be

interwoven with genetic algorithms to optimise the design. Towsey also [49] explores identifying specific musical features in order to help automate a fitness function with music.

From exploring the work above, specifically the role of a user in a GA, those with subjective fitness functions seemed to be more suitable for the context of my project, especially considering the user scale of the project, and the user-centric experience of VR.

Despite there being much research individually into the areas explored above, little HCI research exists that engages with the trio of interactive evolutionary algorithms, VR and musical interfaces. Some examples involving pairs of both are explored earlier on. As such, some consideration about how to best inform the design was needed. One such answer is the Research through Design approach.

2.7 Research Through Design (RtD)

Research through design is an approach to performing research that incorporates techniques from design practices to inform how research is undertaken [53]. The methodology is best described by Zimmerman as the "process of iteratively designing artefacts as a creative way of investigating what a potential future might be" [25]. Thus, in order to explore this new realm of virtual evolutionary musical experiences, prototyping and performing a user study to reveal insights can act as a valuable way of forming research around the topics.

Since the experience I am making is extremely open-ended, working with the RtD approach, it would be logical to perform a more open-ended user study. To this end, I explored the use of semi-structured qualitative studies (SSQSs), and analysis of the resulting studies as a way to explore the recurrent themes that appeared during the studies, and as a tool to aid in evaluation of the project.

2.8 Semi-Structured Qualitative Studies (SSQSs)

SSQSs are an approach to collecting qualitative data in a loosely structured format, often taking the form of semi-structured interviews (SSIs), or general observations [45]. The approach draws from existing work in other disciplines, such as the work of Braun and Clarke [14] in qualitative studies in psychology, and then applies it to the HCI domain. SSQSs fall somewhere between an ethnography and a survey with their sense of structure. An ethnography is defined by Anderson [5] as an observation of work with thorough descriptions, without constraints. Whereas a survey often provides quite a strong structure, with constraints on word-limits and topics. The specifics of SSQSs are explored when relevant, in the Experimental Design chapter.

Drawing from the literature explored above, the next chapter details the process I undertook in creating the system.

Chapter 3

System Design

In this section I expand upon the process of my system design, and how this design is realised, along with any challenges and solutions faced during the process. An example of a user playing with the system can be seen in Figure 3.1.

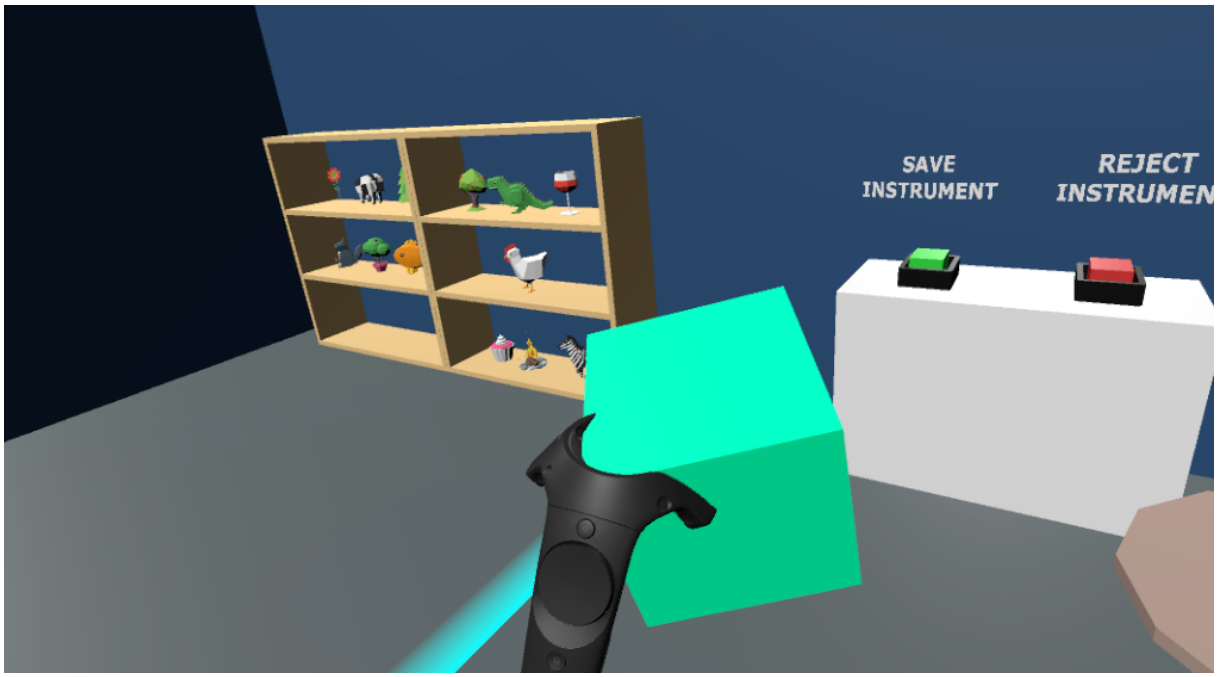

Figure 3.1: An example of a user playing with an instrument in the experience, taken from the HMD view.

3.1 Hardware Specification

The basis of the exploratory environment is in VR, along with controllers to allow a user to interact with the instrument. Therefore, the choice fell between high-quality consumer VR headsets, the main two being the *Oculus Rift* and the *HTC Vive*. The HTC Vive was chosen for its increased compatibility with the development environment, the low system latency [38], and the increased feedback to the user of room space, as described by Boland [12]. The Vive setup consists of a HMD, which is the core of the VR, two room sensors, two hand-held controllers and headphones. These were used in conjunction with a standard VR ready desktop (Dell Precision T3620) to ensure there would be no lag during play, which can contribute to sickness in users [48].

3.2 Software Specification

3.2.1 VR Mechanics

The core of the project exists in the software development. My VR development environment of choice is Unity due to its simple interface, compatibility, and ease of prototyping. The Unity package VRTK (Virtual Reality Toolkit), allows for quick prototyping of VR interfaces. VRTK was used to handle the grab mechanics, buttons, controller management, and UI interaction for this reason. The Vive management, logic, camera space, and controller presence are all managed by the SteamVR SDK.

3.2.2 Musical System

There were several options to construct the musical side of the project. I considered using the default Unity sound engine for ease, but found it to be too inflexible for use. The other options were *Pure Data* and *Max MSP*. Both are dataflow programming languages, in which one creates scripts through creating sound objects and patching them with virtual cables. This flexible environment gives fine-grain control over how audio is manipulated. I opted for Pure Data as it is open-sourced.

In order to prevent the system from descending into auditory chaos, I needed to impose some high level restrictions upon the sound that could be produced by the user, but still wanted it to be open-ended enough that the user would be constantly surprised by how the system is operating. The space of potential sound manipulations is infinite, and therefore I explored a few different options to form the musical core of the instruments.

3.2.2.1 Automatonism

Automatonism [21] is an open-source virtual modular synthesis engine built upon Pure Data. It works in a very similar way to a physical modular synthesiser, with various modules and patch cables, copying their signal flow. Modular synthesis seemed to be a fruitful route to follow, as intricate systems can be set up or generated, yielding complex and unique results with slight modifications in initial parameters. Furthermore, with a relatively small number of modules, the variations in sound would be quite large. A musical sequencer is a device that plays back sound in a certain sequence, usually controlled by a 'clock' that adjusts the speed that the sequence is played back at. By introducing a clock, and a certain sequence of patterns (scales, or modes), this condenses down the infinite space of possible sound into a set of possibilities that are, rhythmically and melodically, more conventionally familiar. The other modules included in the system prevent the sound from becoming too predictable or monotonous.

I explored creating a modular system with various exposed parameters that would be randomised or controlled externally, but I encountered various problems incorporating this system in a form usable to Unity. To this end, I abandoned this route, but the lessons I learnt about structuring the sound generation carried through.

3.2.2.2 Subtractive Synthesis

I wanted a relatively simple synthesiser with modifiable inputs that I could connect to from Unity. Subtractive Synthesis is a method of sound synthesis that starts with simple audio waves, or combinations of them, which are then attenuated by filters to adjust the sound produced [16]. A simple overview of how subtractive synthesis works can be seen in Figure 3.2. The simple subtractive synthesiser that I built works by taking a sawtooth wave and passing it through a VCF (Voltage Controlled Filter), and then a VCA (Voltage Controlled Amplifier). A VCF shapes an audio wave by specifying start, end and Q (resonance at the cut-off frequency) values. VCFs allow for continuous adjustments of values, which is why they were selected. A VCA adjusts the amplitude of the incoming wave: adjusting it with an ADSR (Attack-Decay-Sustain-Release) envelope that shapes the sound.

The in depth details about audio synthesis are beyond the scope of this project, however more information can be found here [17]. My musical core was therefore realised through the construction of a hierarchy of Pure Data patches that mimic the signal flow of a subtractive synthesizer. 12 modes (series of MIDI notes corresponding to a musical mode) were chosen, and connected to a simple sequencer, controlled by a metronome value, which would then be passed through a VCF and a VCA, finally outputting

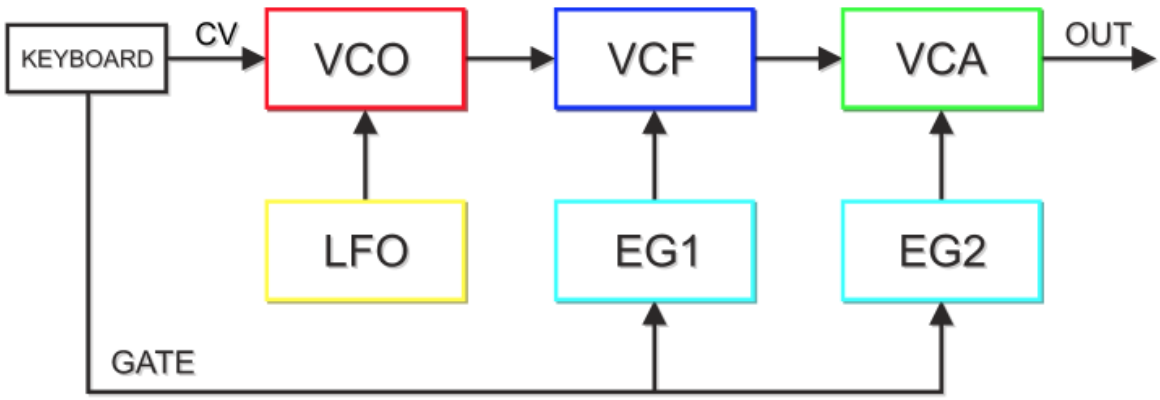

Figure 3.2: Subtractive Synthesis Visualisation [16].

a sound, or series of sounds. The parameters to these parts of the system would correspond to a specific 'instrument', along with a specific chosen parameter that would be the controlled parameter from Unity.

3.2.2.3 Audio System Summary

The final exposed parameters of the audio system are:

- core / metronome
  - scale choice
  - metronome value
  - frequency / scale note
- VCA envelope
  - attack
  - decay
  - sustain
  - release
- filter
  - filter start
  - filter end
  - filter time
  - filter Q value

The final Pure Data patches can be seen in the appendix (C).

3.2.3 Bridge between Pure Data and Unity

While exploring how to best connect Unity to Pure Data, I trialled two options. Firstly, compiling the Pure Data patches (a script, or hierarchy of scripts) into C code with *Heavy*, which one can communicate with through C# scripts [20]. The other option is the embeddable audio synthesis library version of Pure Data, *LibPD*. I chose LibPD as it had a greater compatibility with Pure Data objects. It is imported as a .dll plugin into Unity, and then floats can be sent as input into the objects through a surface-layer C# script.

The two sections of the project are bridged by C# code that sends values to the exposed parameters listed above.

3.2.4 Instrument Interactions / Properties

Having selected the audio input parameters, I needed to explore the space of potential object interactions that could be randomly chosen to map onto an input parameter.

It was important that some part of the project would contain aspects that took full advantage of VR, namely that the experience would be different to conventional, non-VR experiences. I chose that the interaction would not be specifically tied to a user interaction or gesture, but rather that the object's properties would inform the output, and the user would have the freedom to interact with the object in a secondary manner, in the way they saw appropriate. A parallel could be drawn here with conventional instruments, whereby they can often be played in multiple ways, but some ways make more sense than others, or rather more users tend to converge on a specific method of interacting — e.g. plucking guitar strings vs. playing with plectrum vs. using a bow. In the same way, the user was given controllers in order to manipulate the object, and the resulting change in the object's properties would adjust the sound.

Initially I trialled the y-translation (up-down) mapped onto the frequency of a simple oscillator. This worked successfully, and I found it interesting how there were multiple ways of interacting with the resulting object. Gravity, a variable not commonly involved in musical interactions (although perhaps subtly in percussive instruments), seemed to have an influence, as since one could throw the instrument up and down, the resulting audio would arch in frequency, essentially following a one dimensional mapping of a parabolic arc onto the adjustment of the frequency parameter. This surprised me, and I was keen to explore this further in the context of the user study. As the y-translation had this effect, I also wanted to explore how other factors and properties could have secondary effects. To this end, I decided to include properties of translation, rotation and velocity, which would allow for a broad space of interaction.

The final properties of the instrument that can be chosen are:

- position
  - world x translation
  - world y translation
  - world z translation
  - translation vector
- rotation
  - object x rotation
  - object y rotation
  - object z rotation
  - rotation vector
- velocity
  - object x velocity
  - object y velocity
  - object z velocity
  - velocity vector

3.2.5 Genome

A metaphor was needed for the representation of an instrument, and since the ultimate aim would be to evolve these instruments, representing them as a genome made the most sense.

An example genome can be seen below.

$$\underbrace{1\ 0\ 1}_{\text{control params}} \quad \underbrace{64\ 64\ 64}_{\text{scale, metro, freq}} \quad \underbrace{64\ 64\ 64\ 64}_{\text{env params}} \quad \underbrace{64\ 64\ 64\ 64}_{\text{filter params}}$$

Figure 3.3: A snapshot of the genome representation shown inside the experience.

The first 3 parameters range between 0 and 3, and specify which of the parameters will be controlled by the instrument in Unity. It also specifies which of the above object properties will be selected to be mapped onto the other selected audio input. The next set of parameters refer to the choice of scale that will be sequenced, the clock / metronome speed and the frequency of the object (steps inside a scale). The other sets of numbers refer to the parameters of the envelope and the filter as specified above. All parameters apart from the first 3 range between 0 and 127, as these correspond to MIDI notes, and it is the most commonly used range in Pure Data.

This interwoven system of audio inputs, object parameters, and specific genome structure is the core of the system. The specific genome describes exactly the sound that is being produced, along with what property and parameter are chosen to adjust the sound. A representation of the genome is included in the experience, so the user may have some feedback on how the instrument is changing. An example of this is seen in Figure 3.3.

3.2.6 Generation of Instruments

As explored in the supporting material, I concluded that the best way to combine GAs and musical interactions would be with a subjective fitness function, whereby the user specifies their preference for a specific instrument, and this is used to indicate whether an instrument will pass onto the next generation.

Initially, I needed to generate a set of instruments that could be interacted with by the user to determine which to evolve. This was a fairly easy task since the genome had already been created. The C# script would randomly create a genome between the specified ranges.

3.2.7 Unity Scene

Since the experience was to be in VR, there needed to be an area in which the user could interact. I initially set the scene outdoors, a scene with some trees and a tent as I thought that this would en-

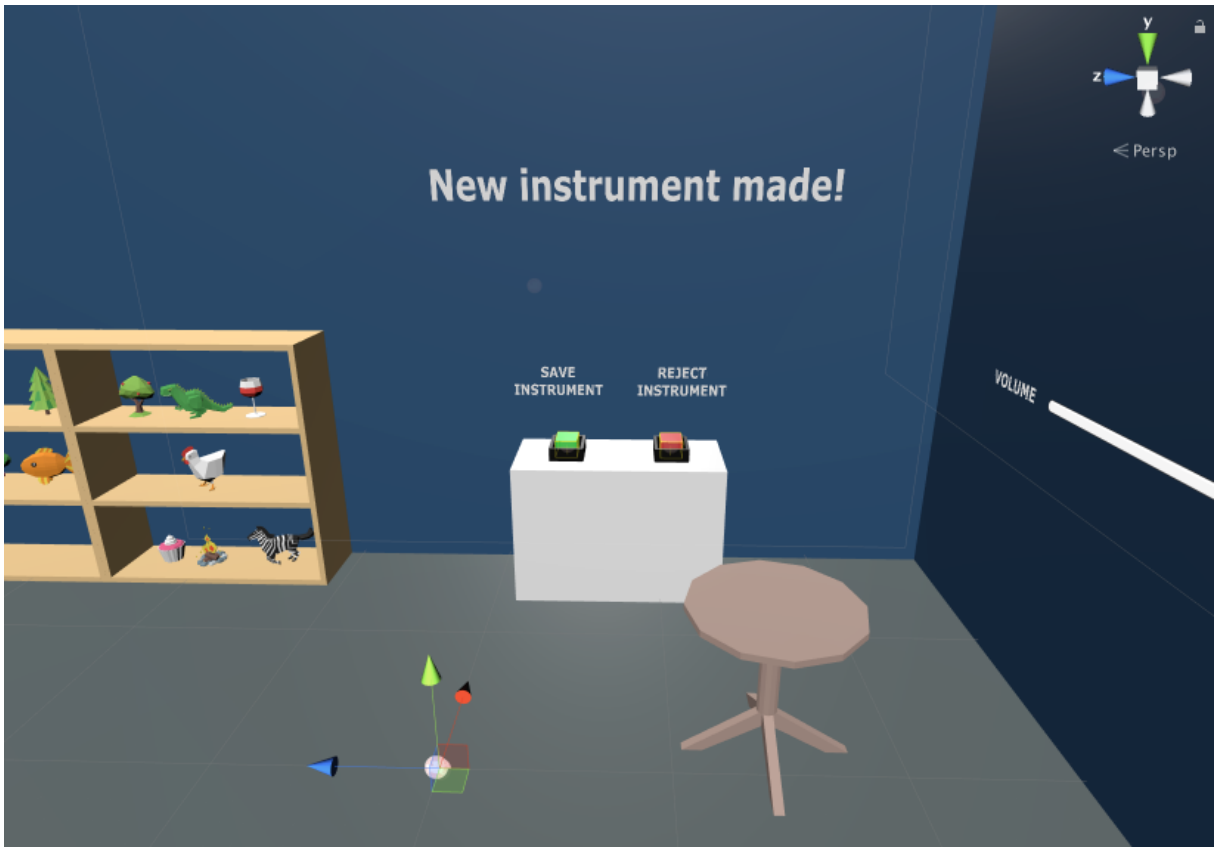

Figure 3.4: A snapshot of the buttons in the Unity scene, and associated pop-up text.

courage the user to be flexible with their surroundings. However, the Vive works by setting up a user area space correlating to the physical space the user inhabits, with a virtual fence that shows throughout the experience. For this reason, I thought it would be more suitable to create a room that fit the physical space. I wanted the room to have a casual, laboratory feel, with not too much surrounding to distract the user. When trying to decide what to populate the room with, I had the choice to opt for more realistic / lifelike assets, or to choose lower resolution assets. I chose to go with lower-fidelity assets, thus opting for a more game-like experience for the user, as I felt this would encourage the user to interact in a more playful way. I would later test this assertion in my user study. Google Poly [1] is an online repository of low-poly 3D objects, under the CC-BY licence, and therefore free to reuse or modify. I selected some suitable props, including a simple table and a bookshelf to add some character to the scene, along with walls to mark out the area the user can interact within. The instruments sat on the table in a clear and obvious manner, so it was simple for the user to understand what to interact with.

User interfaces need to be treated differently in Virtual Reality in comparison to non-VR experiences [6], due in part to the added perceived depth of text. Often it's equally useful to draw from road sign and navigation design in this context, as the items are perceived to occupy real space, as well as existing work on user interfaces on flat screens. For this reason, I decided to experiment with 'physical' VR buttons as means to receive user input, as opposed to using a pointer and screen method more common to flat screens.

VRTK (Virtual Reality Toolkit) is a package that allows for easy prototyping of VR controls, interactions and movements in Unity. Using this, I assigned the controllers, so the user would have a 3D representation of the controllers inside the virtual space, therefore making it easier for them to interact with objects, and the instrument. Also, from this package, I created 2 buttons, realised as cuboid shapes that the user would have to physically de-press with their controllers to trigger an action. These buttons can be seen in Figure 3.4.

For the actual instrument, a simple cube was prototyped and created as a prefab that would be initialised as the instrument, while acting as a RigidBody — a Unity class that allows physical laws to act

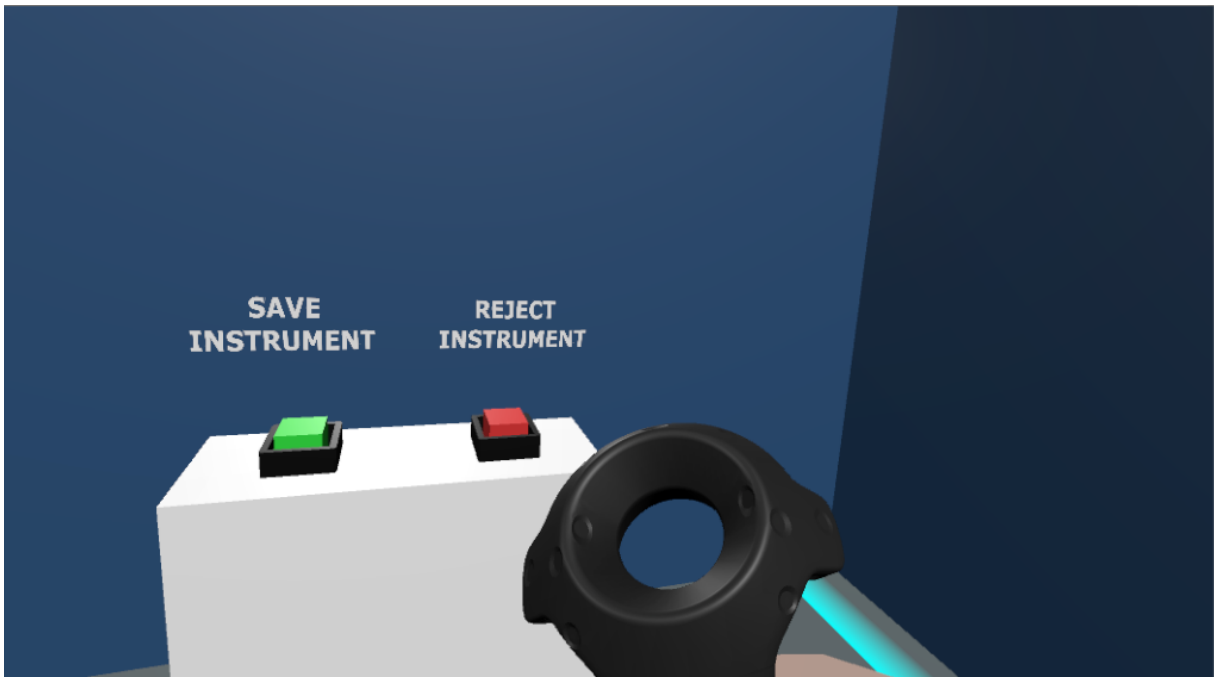

Figure 3.5: A screenshot from the headset in action, after the experience has just began.

upon an object as a rigid-body, meaning that it would be subject to gravity and momentum. A script was written that would collect all the properties of the cube, live, such as its position, rotation, and velocity. All the possible parameters were stored in an array, and the first part of the genome would act as an index array to access the relevant parameter.

To add clear variation to the instruments, a random colour was initialised with each new instrument. Clearly, there currently wasn't much visual feedback about the instruments, but this is a theme I would explore in my user study, to assess its relative importance.

3.2.8 Experience Initialisation Process

On initialisation, a random genome is created. This is realised in code through a 'Genome' C# class that stores the relevant parameters. An object is instantiated from the outlined instrument prefab, with Rigidbody mechanics. From this, a LibPD controller class instance is created, which manages the initialisation and control of the Pure Data patch. The specific audio input parameters to the patch are stored in an array, and the first part of the randomly generated genome acts as an index to the array, thus specifying which parameter will be controlled by the randomly generated object property index. The code that comprises the scripts can be found in the appendix (B).

Therefore, when the player puts on the headset, they see a scene as shown in Figure 3.5. This includes visualisations of the controllers. A single instrument exists on the table, and the user may interact around and with it as they choose to. When a user passes a controller through the instrument, it changes colour to indicate that the controller is inside. If the user presses the trigger on the back of either controller, while it is held down, the instrument acts as a child of the controller — i.e. it has been grabbed. When the trigger is released the instrument is dropped, but since it acts as a rigid-body it conforms to gravity and maintains any momentum it may have. This allows a user to control the instrument in any way they choose: throwing it up and catching it again, rotating around, waving it around, moving it up and down, holding the object still while physically moving in the space, bouncing it off nearby surfaces, or many other forms of interaction. In addition to this, if the trigger is held before the user inserts the controller into the instrument, and they push against it, the controller acts as a rigid-body, thus allowing a user to push, or nudge the instrument around.

On the left of the user are two buttons, one green, to indicate the saving of the instrument, and one red, which indicates that the user rejects the instrument. These can be seen in Figure 3.4. The buttons

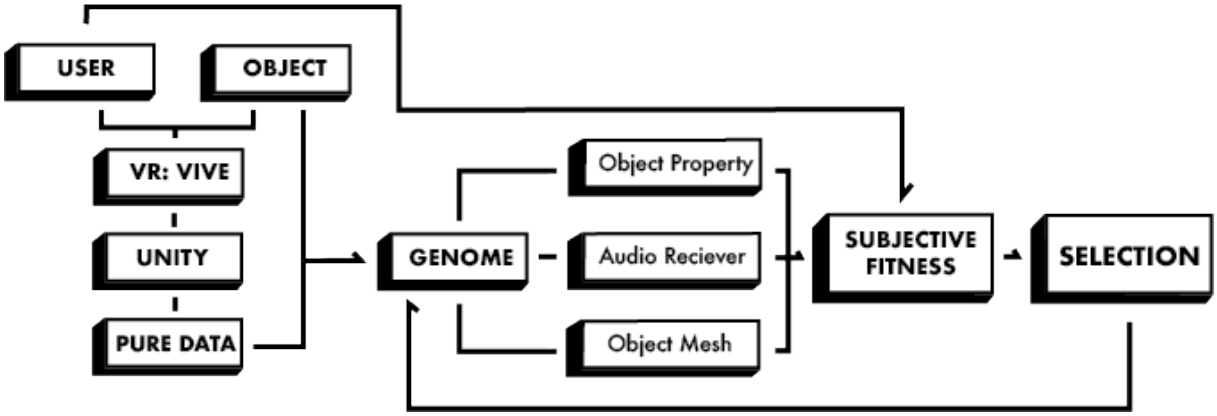

Figure 3.6: A flow diagram of the system.

consist of cubes, that when pressed, trigger the relevant action. The buttons can either be triggered by turning the controller into a rigid-body (by holding the trigger when not in contact with any objects), and pushing downward, or may even be triggered by the instrument itself.

If the save button has been pressed, the genome of the instrument is added to an array of saved genomes. In either case, the current instrument object, and associated script-objects (genome, libpd control) are destroyed. Now, if the evolutionary limit hasn't been reached, a new random genome is generated and presented to the user, in the same way as above. A new instrument rigid-body object is generated on the table, for the user to interact with. If the evolutionary limit has been reached, the evolutionary process starts. In all cases, text appears for 5 seconds above the buttons, indicating what action has been taken.

3.2.9 Evolution and Mutation

The evolutionary limit specifies after how many instruments have been saved the evolutionary process occurs. Random genomes are generated indefinitely until the user selects a subset they like. The crossover and mutation process then are triggered. The crossover algorithm chosen is a uniform crossover. It can be visualised in Figure 2.4. The genome is split into its 4 constituent parts:

- the control parameters
- metro parameters
- envelope parameters
- filter parameters

For each pair of parent genomes, the crossover algorithm splits each into two, and produces two offspring, each with 50% of each parent's genome. Due to the nature of the exploratory project, the current generation, or 'parents' were not included in the new generation. In addition to this, some offspring's genomes are also mutated, by introducing some probabilistic randomness to the various parameter numbers, which occasionally introduces some variation to the evolved children, following the same pattern as natural evolution. This helps to prevent potential avenues from being cut-off early, and to allow a user to navigate a larger space of instruments.

Once the evolutionary process has been completed, the user is alerted to the generation number via the pop-up text, and they are then told which instrument is being loaded from the evolved instruments. They may then proceed as before in saving or rejecting instruments based on their personal preference.

An overall workflow diagram for the logic of the system can be seen in Figure 3.6. As the system was now complete, the next chapter details the process undertaken in designing the user study.

Chapter 4

Experimental Design

With a basic prototype completed, the next stage was to perform experiments in which users are asked to interact with the system, and their responses are recorded, transcribed, and analysed for recurring themes. The following section details the decisions I undertook in designing and ensuring that the experiment conformed to the expected standards, along with any issues I faced, and solutions provided.

4.1 Study Design

As mentioned briefly in the Contextual Background chapter, Semi-structured Qualitative Studies (SSQSs) are a way of collecting qualitative data in a loosely structured format [9]. I used some common methodologies, explored below, to inform the design of the study.

4.1.1 Planning SSQSs

The PRET A Rapporter framework (PRETAR) described by Blandford [10] gives a basic structure for designing, undertaking and reporting SSQSs. In this, the key stages described are:

- Have a clear purpose of study.
- Keep in mind resources and constraints.
- Work with any ethical considerations.
- Decide on techniques for data gathering.
- Consider appropriateness of analysis techniques to data.
- Ensure reporting addresses purpose of study, and conveys in appropriate manner.

I applied this framework to the study I created, the process of which is outlined below in more detail.

4.1.2 Preparation

The technical design of the experiment was fairly minimal, as I was simply asking users to trial my new environment. As I was conducting an experiment where I would subject the user to a VR experience, and then record their audio, I had to ensure that the users fully understood what was expected of them, as well as submitting my experiment and the appropriate paperwork for external review by an ethics committee. I asked users for their consent with an appropriate form, as well as giving them a participant information sheet that detailed what they would be expected to do during the experiment. These forms can be seen in the appendix (D). The ethics reference number is 65421.

Subject ID	Age	Gender	Musical Experience (ME)	VR Experience (VRE)	Pseudonym
VR01	22	F	3	3	Annie
VR02	22	M	4	4	Bob
VR03	22	M	2	5	Carl
VR04	21	M	2	4	Dylan
VR05	21	F	3	3	Eva
VR06	26	F	3	4	Flo

Table 4.1: A table of the participants of the experiments, and their collected demographic data.

Number on Scale	Level of VR Experience (VRE)	Level of Musical Experience (ME)
1	No experience at all.	No experience at all.
2	Heard about VR technolog.y	Like listening to music, but don't play any instruments.
3	Used once before (demo, friends, etc.)	Play an instrument / produce / DJ (etc.).
4	Used multiple times, in different contexts.	Play more than one instrument.
5	Own a VR headset.	Professional player / master of several instruments.

Table 4.2: Table showing the ranges of VR and Musical experience.

4.2 Participants

4.2.1 Background Data

As well as performing the interviews, I collected some minimal background data on the participants, asking their age, gender, musical and VR experience, in order to try to minimize any external factors that may influence the outcome of the experiment. This simple questionnaire contained questions with a simple scale, where the meaning of each of the responses was clearly indicated above. This sheet may also be seen in the appendix (D).

In recruiting participants, I simply sat at a central location with a poster (seen in appendix — D) indicating my study, and offering re-compensation of a cookie to encourage participants. Since there would, eventually, be a large body of transcribed text for each individual, only a relatively small amount of participants were needed. I also noted the spread of experience (taken from the anonymised background data), both musically and with VR, so that I could try to recruit participants with different levels of experience if they tended to converge at one end of the spectrum.

The experiments were run across one week. In total, there were 6 participants, with resulting audio spanning between 15-20 minutes for each. Therefore, approximately 90 minutes of audio data was collected and transcribed during the study. The experiments were conducted in the Animation Lab, in the Merchant Ventures Building. All participants were re-compensated for their time with a cookie, or sweet treat of equal value. All participants were in the age range of 18-30, were all current, or past, students and staff of the school. There were a range of levels of VR experience and musical ability. The final 6 participants and their respective assigned pseudonyms can be seen in Table 4.1. The information that the users were given for each number in the scale is shown in more detail in Table 4.2.

4.3 Data Collection

4.3.1 Think-Aloud Protocol

Users were given very simple instructions, and then asked to partake in the experience for around 15 minutes. As part of the information sheet, the users were instructed that they would need to 'think-aloud'. Blandford [9] defines the process of think-aloud as "users of a system articulating their thoughts as they work with a system". This is a fairly uncommon technique for many people, so they were given an opportunity to try this vocalisation beforehand. Participants were asked to vocalise their thoughts about the colour of the room, and to act as if they were alone in the room. Despite this initial practice, some participants would often forget to vocalise their thoughts, or would get stuck on one specific part of the project.

To combat this I occasionally would remind and prompt them to vocalise their thoughts on specific topics.

The 'think-aloud' vocalisation would happen whilst users were inside the experience, giving them the chance to relay any thoughts they may not remember or picked up on once they had stopped engaging with the experience. After this, the users took part in a semi-structured interview, where there would be a rough topic guide. As part of this, any avenues that were of particular interest that they raised during the experience, or that came up during the interview were pursued in the questioning.

4.3.2 Semi-Structured Interviews (SSIs)

Semi-structured interviews are a format for conducting interviews for qualitative studies, whereby a topic guide is used to give a loose structure to an interview but whereby any topic of interest that comes up is explored further [9]. The interviews often occur after the experience has taken place.

4.3.2.1 Semi-Structured Interview Topic Guide

In creating the topic guide for the study, I first took part in the experiment, trying to consider what immediate questions sprung to my mind whilst I was participating. In addition to this by re-reading the NIME papers, I tried to note important themes that came up when trialling new interfaces. I also drew upon the old adage of 'who, what, when, where, why?' if I hit any roadblocks. Finally, some questions made sense to ask, such as a comparison between VR and non-VR, or between my project and a conventional musical instrument.

Phrasing the questions so they were not leading, and therefore unbiased took a few iterations of design. The questions also had to use clear language to not distract the user, or mislead them in any way. The final, loose topic guide consisted of the following questions:

- So what did you think was happening?
- What were your first impressions? (Did these shift as you spent longer inside the experience?)
- What did you think of interacting with the instrument?
- How easy was it to use?
- How does this compare to using a conventional instrument? (How does it compare with a physical instrument / object?)
- How does the VR experience compare to a non-VR experience?
- Is there anything you would add to the experience?

4.4 Data Analysis

4.4.1 Planning Data Analysis

Thematic analysis is described by Guest [26] as a technique of analysing qualitative data through the targeting of recurring themes in data. Historically taken from the work done in the psychology field by Braun and Clarke [14], their approach consists of the process of iterative 'coding' of data to establish patterns, in 6 main steps, as seen in Figure 4.1.

Braun and Clarke [14] identify a theme as something that "captures something important about the data in relation to the research question, and represents some level of patterned response or meaning within the data set". They go on to try to identify a specific number of data examples that can help give strength to a theme, however they conclude that no rigid set of rules can be applied, and rather they advise to maintain some flexibility in identifying themes, and sub-themes.

TABLE 1
PHASES OF THEMATIC ANALYSIS
(ADAPTED FROM BRAUN & CLARKE, 2006)

	PHASES	DESCRIPTION OF ANALYSIS PROCESS
1	Familiarising myself with data	i) Narrative preparation, i.e. transcribing data ii) (Re-)reading the data and noting down initial ideas
2	Generating initial codes	i) Coding interesting features of the data in a systematic fashion across entire data set ii) Collating data relevant to each code
3	Searching for themes	i) Collating codes into potential themes ii) Gathering all data relevant to each potential theme
4	Reviewing themes	i) Checking if themes work in relation to the coded extracts ii) Checking if themes work in relation to the entire data set iii) Reviewing data to search for additional themes iv) Generating a thematic "map" of the analysis
5	Defining and naming themes	i) On-going analysis to refine the specifics of each theme and the overall story the analysis tells ii) Generating clear definitions and names for each theme
6	Producing the report	i) Selection of vivid, compelling extract examples ii) Final analysis of selected extracts iii) Relating the analysis back to the research question, objectives and previous literature reviewed

Figure 4.1: The 6 phases in coding for thematic analysis, by Braun and Clarke [14].

4.4.1.1 Inductive vs. Deductive

Braun and Clarke [14] identify the differences between analysing inductively and deductively. An inductive analysis is one where the themes are data-driven: the coding process occurs without pre-conceptions, allowing the themes to arise from the data itself. Conversely, a deductive approach is based on a theory — there is a clear theory it is applied to the data [18]. These definitions are also reinforced by Boyatzis [13]. With inductive analysis, it's extremely difficult for the researcher to completely remove themselves from their prior thoughts, or immediate assumptions that sprung up before doing, or whilst undertaking the experiment. Since I am doing an open-ended study, and I am trying to observe what comes up from the data, and therefore I am undertaking inductive analysis.

4.4.1.2 Semantic vs. Latent

Boyatzis [13] also describes levels of theme identification: semantic and latent. A semantic theme merely takes what the data says on face value, no deeper meaning is taken. Although this can lead to less depth, it can give a solid representation of the whole dataset. In contrast to this, latent themes bring forward underlying ideas and patterns. I am performing latent thematic analysis as I would like to abstract from the actual data I have collected, and focus on what trends and ideas lie beneath the user responses.

4.4.2 Data Processing

In order to get some first initial impressions, while I was transcribing, I would note down anything I deemed to be a 'recurring theme' throughout the process. This would be anything that was repeated multiple times, or particularly stressed by the user. I would later use some of these impressions to form themes, or sub-themes. I wrote these loose themes on post-it notes, so I could keep it clear as to which themes were coming up, whilst trying to minimise my own personal interests so that I could process the data in an unbiased manner.

The audio of both parts of the experiment was recorded for later analysis. After the experiments had all been conducted, the audio was transcribed using a webapp (transcribe [4]), so that it could then be coded and analysed. The audio stream was transcribed fully, i.e. everything heard was transcribed. Samples of the resulting transcriptions can be found in the appendix (E).

After the transcribing was complete, I imported the newly generated transcripts into Nvivo [33], a qualitative data analysis (QDA) piece of software, which encourages you to code your qualitative dataset to classify and sort the information.

4.4.3 Coding

Nvivo defines 'coding' as a way of "gathering all the references to a specific topic, theme, person or entity" [2]. This is the preliminary stage that is taken when trying to pull out insights from data. It consists

of identifying patterns through an iterative process, where certain parts of the text are coded as being part of a specific theme. This process is then done a few times in order to refine the themes and identify smaller sub-themes. The coding process is interwoven with the thematic analysis.

4.4.4 Thematic Analysis

The resulting codes help to reveal what is happening at a higher level with the data. As described earlier, I performed an inductive, latent thematic analysis. In particular, I chose an iterative strategy for performing the thematic analysis: I identified codes, and then attempted to identify basic themes, and then formed more abstract themes. After this, I went back to see if the codes could be developed further. Throughout this process I also aimed to identify if there were any connections between the themes. After this process had been done a few times, I then started to develop a narrative with the data, and eventually ended up with more high level themes. My findings are presented in the following chapter.

Chapter 5

Results

> "I'm not really thinking anything, I'm just playing with it."
>
> *Annie*

In the following section I present the themes that arose whilst conducting the thematic analysis, and explore them in the context of the transcribed data and the literature. During the process, the key themes were in 5 areas:

- Control
- Comparison to Real World
- Immersion
- General Usability
- Limitations

Each theme is explored in more detail below. In order to be able to interpret the ranges of VR and musical experience, Table 4.2 details the ranges, and corresponding information that the users were given on their questionnaire. Throughout the results, the participants are referred to by their pseudonyms, seen in Table 4.1. Figure 5.2 shows an overview of the codes that were generated from Nvivo, and the proportional size of each number of references. A picture of a user interacting with the system is seen in Figure 5.1.

Figure 5.1: A (happy) user interacting with the system.

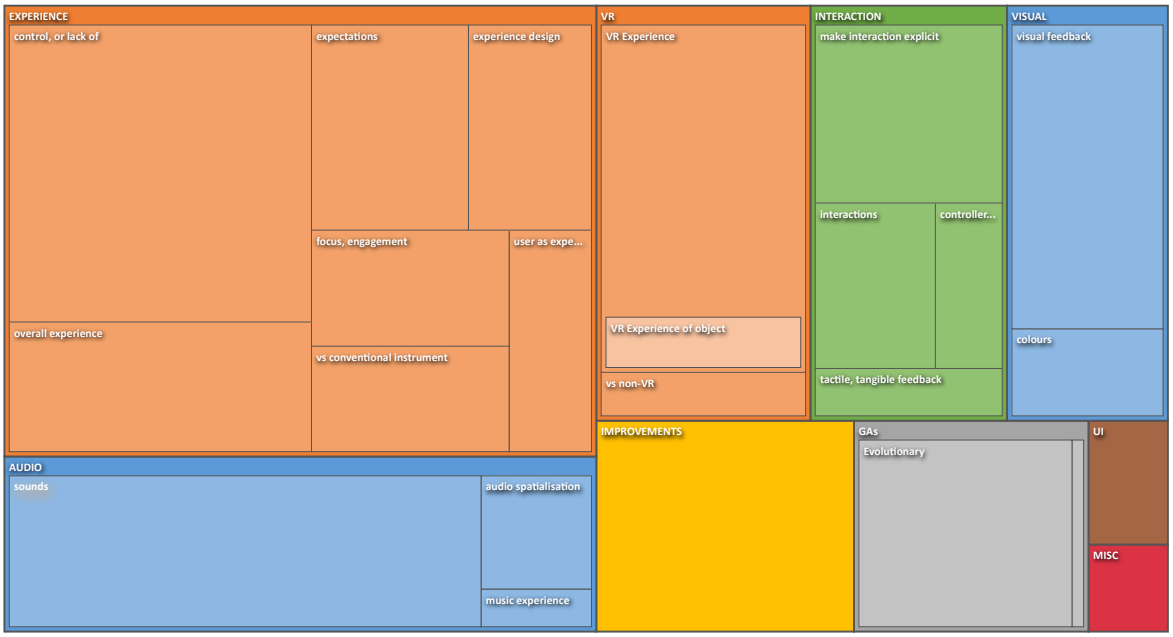

Figure 5.2: A hierarchy diagram showing the nodes and sub-nodes, produced in Nvivo.

5.1 Control

A strongly recurrent theme that came up throughout the experiments were the varying levels of control that users had, over different parts of the experiment. They were mainly grouped around varying opinions of agency directly over the sound, the direct way of controlling the experience that the users were provided with, and around the overall evolutionary process. These can be explored as different 'grains' of control, from the low level direct interaction, to the more removed, implicit control that the users had as part of the evolutionary algorithm.

5.1.1 Agency

Many participants were left feeling frustrated by the fact that they felt that they were having no direct influence over the output sound, or that it took them too long to identify what the control was. Annie stated that they "*thought when they threw it, it was gonna get louder*", and they "*preferred the ones [instruments] where it was more obvious [the interaction]. Because it made you want to interact with it more*".

Bob went on to describe the process differently, describing when they'd "*experimented with it, they could identify the . . . axis of interaction*", and that "*then it was easy*". Dylan stated they couldn't "*really tell what's changing it when [they] ... move the thing, or throw it or whatever*", and even more explicitly said "*the instrument sounded the same when it was sat on a table as to when I was holding it*", and that they "*didn't feel like [they] were playing the instrument, because [they] couldn't tell any link between what [they] were doing and the sound that was being made*". Along the same lines, but at a slightly different angle, Flo said that their lack of direct influence wasn't "*that important to [them], but [they wanted] them to do a bit more when [they threw] them against the walls*". For this user the lack of direct control wasn't essential, and this may have come about from a different perspective upon the experience. Flo had a VRE of 4, which implies that they're very familiar with VR experiences in general, and then perhaps saw it more as a game rather than a solid interface for interaction. This is reinforced by Flo's desire to use the instrument as a "*projectile to hit them [the unrelated objects in the scene]*".

Drawing again from the work of Steuer [46], under the role of 'interactivity' in increasing telepresence, this theme would fall into the 'mapping' area, as users appear to be finding inconsistencies on the mapping between their actions (moving it up and down, or side to side), and the effect on the music. Since I am

Type of controller interaction	Effect	Realisation
Pushing Buttons	Save or Reject Instrument	Hold trigger and push downwards, or alternatively trigger with object.
Grabbing Cube	Cube is made child of controller	Insert controller into object (object is highlighted in different colour), and press and hold trigger.
Pushing Cube	Cube is pushed around	Hold down trigger and push against cube.

Table 5.1: Table of possible controller interactions user can make using HTC Vive Controllers.

considering this from the perspective of a musical interface, this point is essential — users felt more satisfied when they felt like they had a direct effect upon the music. Carl stated "*if that change in sound was really obvious, you could . . . control it better*". As explored in the System Design section, there are 12 possible object properties (4 for translation in 3 axes and 1 for the resultant vector, 4 for rotation with the same 4 properties, and 4 for velocity with the same), and 11 possible sound effectors (4 for filter, 4 for env, 3 meta-parameters). A suggested obvious parameter by Dylan is shown in their statement "*if there was something that felt like . . . as you moved it, you could tell. And I guess the obvious one is pitch, because you notice that, a lot*". Bob found "*some more intuitive than others*", especially pointing to "*when they raised it higher, it [the sound] was getting higher*". As demonstrated above, a pitch mapping had a 1/11 probability, and the translation y had a 1/12 probability. Therefore, this combination was relatively unlikely to be chosen. A more abstract way users voiced their feelings about agency were through their influence in the evolutionary process.

5.1.2 Control over Evolutionary Process

A key part of the novelty of my approach was the introduction of the user as a part of the evolutionary process of refining instruments. As indicated by my hypothesis, I was interested in seeing the effect of unification of VR and evolutionary algorithms in creating engaging musical interaction. Many users found that they were having control over what was happening, but that the level of control was quite loose. Bob said the instrument did "*sort of . . . sound like a combination*", implying looseness. Dylan followed this with "*you could kind of tell that some instruments were related to the previous instruments. I guess it was slightly hard to remember*". From this quotation we can see that it wasn't always easy to remember what the progression had been, as users were often trialling many instruments (often between 20-25).

However, Dylan also described the sounds as "*getting better*", and that "*some of the ones that you'd said were good before did show up again ... the ones you'd hated had gone*". This shows a refining of instruments. The consideration on this is that perhaps if users experimented for a longer period, they might find that the instruments get further refined to their liking. All users noted that they felt like they had a control over the selection of instruments, and many shared this view of 'cutting off extremes'. Flo described how "*some of the extremities of things [they] didn't like had gotten rid of ...*", but also went on to describe in an instance that an instrument was "*great! This is my favourite instrument so far*".
On a much lower level, users also discussed how they used the hardware controllers as a means of control.

5.1.3 Direct Control with Hardware Controllers

The controller interactions that the participants used to interact with the instrument formed the core of the experience. As all levels of VRE ranged between 3-5, users were familiar with how to interact in VR. In Steuer's telepresence diagram, this corresponds to the main 3 areas under the 'interactivity' umbrella: 'speed', 'range', and 'mapping' — in particular mapping. Users were given a quick overview before the experiment began on how the controls were operated. The main interactions are listed in Table 5.1.

Overall users said they found the controllers easy to use, and none raised any major qualms about the interactions. In fact many described the experience positively. In addition to the 'primary' interactions

described in Table 5.1, users could perform secondary interactions, such as throwing the cube around, bouncing it off walls, juggling it, spinning it etc. They had a large amount of freedom in this area, and many users chose to interact in different ways. A common interaction would be to throw the cubes up and down, or bouncing it off the walls and catching it. Carl said they were "*very easy. Very natural*", and Eva said they were "*really easy to use*". Flo correlated this in saying they were "*satisfying*". Steuer's notion of 'speed' is covered by Carl in saying "*there wasn't any lag*". This contributed to their overall engagement in the experience. Users also explored the kinds of visual feedback that arose as a means to give them more control.

5.1.4 Numerical-based Feedback as a Means of Control

Bob suggested the potential for "*changing numbers*", or even "*a graph*" as part of the user interface, to demonstrate what was changing when the instrument was being moved, thus increasing the user's level of control. Throughout the experiment the genome was displayed on the wall in front of the user, in a raw string, 11 digit format, but many users commented on not looking at the genome. Flo said they "*stopped looking at them very quickly, because I was sort of like, 'oh, numbers'*". They then pointed towards the potential for "*bar-charts, or some other sort of visual method*". Overall from this it seems that the genome was nebulous to users, and didn't mean much, therefore minimising their feeling of control.

In many of the above sections, the theme of control is informed by users drawing analogies between this experience and the real world, which was another recurring theme.

5.2 Comparison to Real World

As with any VR experience, users drew lots of comparisons between what they were experiencing and what happens to them in the real world. This was broken down into a few key sub-themes: relating to the kinds of sounds being produced, their spatialisation throughout the experience, the influence of any previous experience with music, and comparisons with conventional instruments.

5.2.1 Types of Sounds being Produced

A key part of the interface I was creating were the sounds that were being produced. As outlined in the System Design section, the audio was created in the form of an interactable Pure Data patch, in which a simple subtractive synthesiser was built, and the parameters of the subtractive synth could be modified by the users, and/or genome.

In general, many participants found that the space of sounds that could be produced was quite limited. However, a few other users thought the sound space was quite large. Therefore, I overall found that there was no consistent answer. However, users who had more familiarity with conventional instruments tended to describe the sound space as "*similar*" (Dylan, Eva). Dylan (ME 4) said "*all the sounds are quite hard to distinguish*", and that they'd prefer "*something less electronic-y*". Conversely, one user, when explicitly asked if they thought there was a large sound space replied "*Yeah. Definitely.*". One user described the sounds as "*like when you play with the keyboard in GCSE music*", presumably implying that the sounds were quite esoteric, given the unpredictability of classic 'old-school' keyboards, and the variation in their 80s style sounds. Some other terms that came up to describe the sounds were: "*screechy*", "*background fuzz*", "*bubbling*", "*bad bagpipes*", and "*jolly*". The depth of the sound, or its position in space was also discussed.

5.2.2 Audio Spatialisation in Environment

Several users commented on the fact that they expected the audio to be coming from the instrument itself, and therefore expected it to move around, or be spatialised according to its position. Annie stated they kept "*wanting to put it to [their] ear*". The audio coming from the cube would seem to increase the user experience of being an active influencer of the sound. Dylan explicitly said: "*I do think audio coming from the cube would give you more of an idea that interacting with it is what changes the sound*", and Eva said it'd be "*much more . . . easy to see how the change*" was being affected. Drawing upon the work of Steuer [46] of factors influencing telepresence, I believe that this would increase the 'vividness' of the audio, by increasing its depth. This may also be drawn from user's expectations from conventional instruments.

5.2.3 Comparison to a Conventional Instrument

In general, very little comparison to a conventional instrument was found. Every single user used the word "*different*" when asked for a comparison. Bob pointed towards it being "*easier*", and more "*rewarding ... because you can make it [the sound] really quickly*". This notion of ease is reinforced by Flo, referring to conventional instruments with a "*degree of skill involved*", and with this experience describing a "*very low barrier to entry*". The idea of reward is contrasted by Flo in saying that of a conventional instrument there is a "*level of satisfaction that comes with playing it ... and knowing that you are responsible for music*". Therefore, nothing conclusive was found about the reward of the different interfaces, but I can ascertain that they are "*different*". Users didn't delve into this topic very much, and preferred talking about other topics. The level of user's experience with different kinds of music, and conventional instruments was also explored.

5.2.3.1 Effect of Previous Experience with Music

A few users pointed to their inexperience with synthesised music, with respect to both listening to and creating. This led to them struggling to give answers to some questions. Bob said "*it'd be easier to give more answers if I had ... a lot more experience with synthesised music*".

One of the key reasons users are interested in VR is the potential for immersion. Immersion gives users a chance to experience some things they experience in the real world, taken to extremes.

5.3 Immersion

As a VR experience, immersion, or engagement was another key theme throughout the experiments. Many users discussed in detail factors that left them feeling immersed, or potential improvements they felt would add to their immersion. Integrated into these themes were the notion of tangibility, different forms of colour and shaped-based feedback, and comparisons with non-VR experiences as factors influencing immersion.

5.3.1 Tangibility

A recurrent theme throughout the experiments was the notion of tangibility, or having haptic feedback from the experience. Several users pointed towards this increasing their immersion inside the experience. Annie pointed towards "*not feeling the instrument*" as a reason for feeling less in control, and that they'd feel more "*inside the experience*" if haptic feedback were involved. Carl (VRE 5) said "*vibration might be a good idea*", pointing towards it as conveying another layer of confirmation when a button has been pressed, reinforcing an action. From this, again it points towards Steuer's 'vividness' in increasing 'telepresence' by adding to the 'breadth' of the experience, contributing to one of the 5 senses as outlined by Gibson [23] — this obviously contributing towards the haptic, or touch system.

5.3.2 User Relation to Experience

Some users felt more like they were inside an experience rather than using an interface. Some users also felt like their role was more implicit, or secondary. Dylan said they "*felt like [they were] the fitness function in [the] algorithm, rather than a player of instruments*". This quote points to a higher level of control, as a chooser of instruments. An interesting point about musical ownership is raised by Flo in the quote:

> *"I felt quite removed from the music I was making. It felt a bit like I was ... if someone listened to the final generation of my cube, I wouldn't necessarily feel like I could take responsibility for it. I would feel like I was a bystander in the experience."*

This suggests that the experience develops by itself and Flo doesn't necessarily feel like they're an active participant in the experience, but merely a bystander. They go on to describe that their "*enjoyment of it isn't being affected generally. And it's nice to have something to do while listening to music. And part of that is throwing nice cubes up and down, and watching them*". This again points to a different dialogue with the interaction, and rather than viewing it as an interface, users viewed it as an experience to partake in. This leads to another discussed sub-theme affecting immersion — visual feedback.

5.3.3 Increased Visual Feedback as a Method of Increasing Immersion

5.3.3.1 Shape-based Visual Feedback

Users Flo and Bob both pointed towards the potential for the instrument itself to "*mimic the music*" (Flo) that was being created. Eva described how some sounds could be "*pointy*", or "*round*", and Bob explored how the instrument "*could be changing shape when you're moving it*". This points to two different representations on the visual domain, neither of which users felt were being capitalised upon enough. The clear improvements that can be drawn from this are that either the shape of the instrument could represent the sound, or could aid in representing the interaction that is being performed.

Dylan elaborated on this idea by describing a "*visual ... movement*", giving the example of the "*cube [having] an up and down arrow ... that tells you as you move it up and down, something is changing*". This is another suggestion that could work, having a UI based indicator of what interaction users need to be performed, and would aid in minimising the discovery time of the interaction that many users found counter-intuitive. Another form of visual feedback is the potential for instrument colours.

5.3.3.2 Colour-based Visual Feedback

In order to add some basic variation to the created instrument, each time a new instrument was created, a random colour from the RGB combinations was created and assigned to the instrument. This results in $265^3 \approx 16M$ possible colours, and there is very unlikely a colour will be reused. Most users didn't pick up on this, except for Flo, who indicated that their "*colour preference [spilled] onto instruments*". When asked further they gave the example of the "*tobacco-green*" (Pantone 448C), which is used on the new UK tobacco packaging as it was voted the 'ugliest colour'. This user said that this immediately put them off playing with the instrument, whereas with "*brighter ones [they were] ... more excited to play with*". This shows that visual fields such as colour can have an implicit effect upon a user's preferences.

A few other users pointed towards extending this idea further, in using the colour as an analogue towards indicating the evolutionary aspect of the experience. This would help address some user's difficulty in remembering which of the instruments had come before, and would further help represent which instruments had acted as the 'mother' and the 'father'. Using colour as another phenotype (observable characteristics produced from a specific genotype, or genome) would also help enhance the visual 'depth' from Steuer's model. Dylan pointed towards doing the "*colour between those 2 [the parents'] colours*", which demonstrates an implementation of this idea.

Overall the above factors help shape the VR experience, but some users commented directly on the effect of VR upon their immersion levels.

5.3.4 Direct Effect of VR on Immersion

Several users pointed directly towards the VR being a strong cause towards increasing their engagement, and feeling of being immersed. Bob described "*good graphics*", Annie describing it feeling "*very real*". Eva described it as "*quite immersive*", and afterwards described how they felt like they'd "*just come out of the cinema*". All of these correlate strongly with my hypothesis that the intersection of the methodologies and technologies aid in increasing engagement and immersion.

Carl, when asked how the VR experience was, replied with "*very engaging*", and elaborated saying, "*if the frame-rate was low, then that [could] cause some kind of sickness and ruin the experience*". Taking from the 'speed' section of Steuer's [46] diagram, under 'interactivity', this correlates from an essentially non-existing lag between user and action, and increased telepresence.

5.3.5 Comparison to a Non-VR Interface

All users were directly asked how the interaction compared to a non-VR experience, such as interacting with a screen via a mouse. The pervasive opinion was that of VR increasing immersion, with Flo saying: "*I think if that experience I'd just done was on a screen I would have lost interest in the picking up and playing with the object much, much faster.*" Eva said she felt like "*[she] listened a lot more to the sounds*", in comparison to a non-VR interface, showing that the visual field may have enhanced the auditory field.

Aside from the VR experience, the use of Interactive Evolutionary Algorithms as a means of user-centric design was also explored in relation to a state of 'flow', or continuous immersion.

5.3.6 User-centric Instrument Choice as a Factor Increasing 'Flow'

Drawing from the literature, Poirson [39] explores the role of the user in instrument design, but with woodwind instruments. I believe this shows that there is merit in the use of subjective fitness functions in shaping an instrument to user's preferences. Again, drawing from Steuer's [46] telepresence tree, allowing a user to act as the fitness function sharpens the 'mapping' towards individual preferences, and therefore increases the strength of the 'interactivity' factor on increasing telepresence. Users informally stated that they could have spent longer inside the experience, and used words like "*fun*" (Bob, Dylan, Eva, Flo), and "*playful*" (Annie, VR6). Annie went on to describe what can be interpreted as a state of 'flow': "*I'm not thinking anything, I'm just playing with it*".

In addition to the more abstract themes explored above, users also gave some direct practical advice.

5.4 General Usability

Another theme relates to the general usability of the experience, specifically around the informational text that was displayed during the experience, and some general limitations that were described by users.

5.4.1 Informational Text

User interfaces in VR present a new set of challenges for users, as explored by Stone [6], who turned towards road sign history to get a better idea on how users process information, as opposed to just drawing from design for screens. Factors such as scale, distance, and contrast, which are not as significantly an influence in flat-screens, are vastly important in conveying information clearly to a user.

Table 5.2 shows some possible informational-text pop-ups users may see during the experience. Several users described how they couldn't see the informational text clearly, and many only remembered it was there when they were prompted. When they realised that it was there, they often found it informative, but many pointed towards how the information could be conveyed in a clearer fashion. Dylan said that the info-text was "*a bit too high up and a bit too big*", and that from their "*view [they] couldn't see when ... pressing the button*".

Informational Text	Purpose
"New instrument created"	Indicates that a new instrument has been made from the first generation, i.e. genome is completely random.
"Generation X, genome evolved"	Shows the number of the generation, and indicates that the crossover algorithm has taken place.
"Instrument number X loaded"	Of the generation that has been created, it indicates which number instrument in that array is being loaded.

Table 5.2: Table showing possible informational text that may be displayed throughout the experience. The text would appear for 5 seconds above the buttons, and then disappear.

5.5 Explicit Improvements

Some users detailed explicit improvements that they would like to be seen, which are presented within Table 5.3. These are all interesting improvements and recommendations that will be crucial in helping to inform future design.

Improvement quote	User	Context
"it'd be cool to have some kind of way of putting tempo in there"	Bob	In describing general improvements
"different locations, where the ... preset instruments were." "you'd have like a percussion bit, and maybe like a synthesis bit"	Bob	When describing the idea of having different sections of the virtual space, each section corresponding to a different part of the overall sound.
"letting the user know how many instruments they can use to create their next generation"	Bob	When describing informally that currently saving 4 instruments triggers the evolutionary process.
"sort out the gravity" *(See Figure 5.3)*	Carl	After a few instruments had been lost after throwing them, and their low mass meaning that the gravity appears very low.
"perhaps the calibration is important"	Eva	When describing that the table, and reaching the object felt slightly unnatural to them. No other users commented on this - user was taller than most other participants.
"different kind of sounds" "maybe just more sounds"	Eva	In describing the sound space as rather limited, and unrelated at all to conventional instrument sounds.
"having a few things to knock down?"	Flo	User attempted to knock down other objects in scene to no avail.

Table 5.3: Table showing the explicit improvements users detailed throughout the user experiments.

5.5.1 Limitations

In relation to limitations, only one key one was explored — the lack of space in the experiment.

5.5.1.1 Experiment Space

At the core of the whole experience lies the virtual reality aspect — arguably the most important since nothing else would be usable without it. All users in my experiment had a VRE of 3 or above, and thus minimising the 'interest in VR as a novelty' aspect of the study. It also means that all users found getting to grips with the actual headset and controller mechanism very easy. A consistent point that came up throughout the experiments was that of limited space. Due to practical reasons the experiment was run in a relatively small place, but not small enough to interfere majorly with the experiment. As a result there were a few "**bang**"s and "**loud thud**"s throughout the experiments, and many users talked about wanting a "*bigger space*" (Annie, Dylan, Eva).

The themes that have been described above are discussed in more detail in the following chapter.

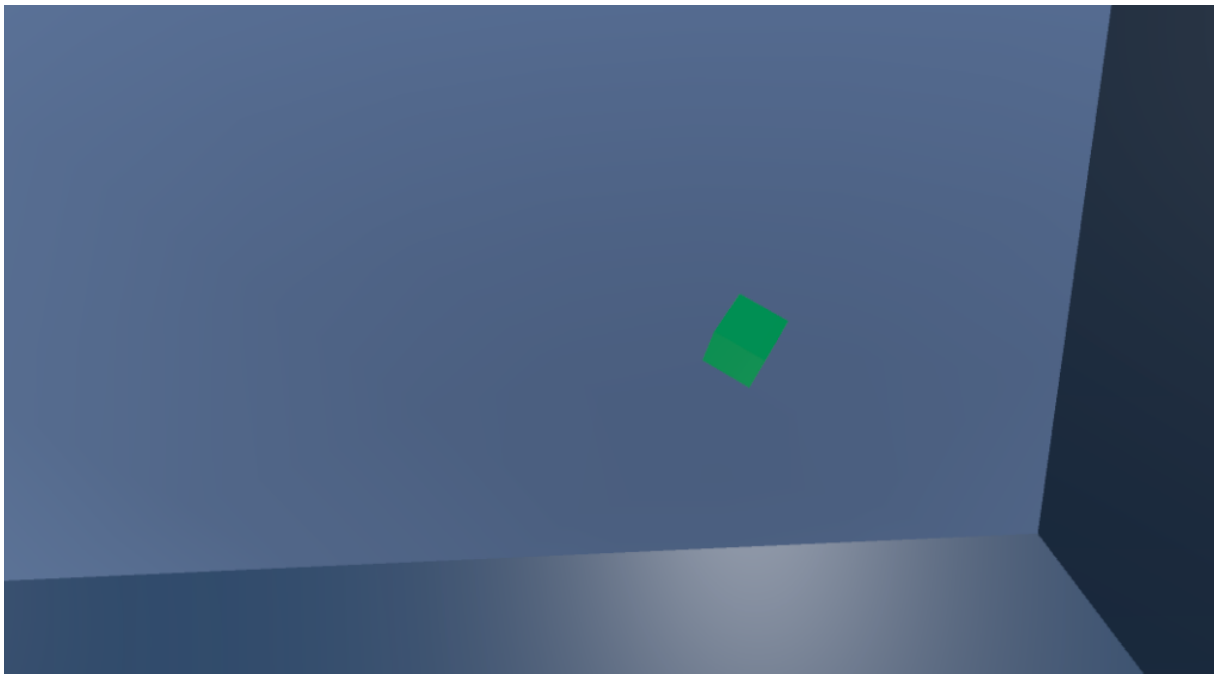

Figure 5.3: An example of how the gravity influenced the instrument's movement, taken from the experiment.

Chapter 6

Discussion

In this chapter I elucidate further on the themes that arose, and explore in more detail the work done, in the context of existing literature. I also go on to discuss the impact of what was raised on informing future work.

6.1 Control

Throughout the experiments, users referred to their feelings surrounding levels of control. In the experience, there were 3 main levels in which control could be exerted: The low-level direct control through the hardware controllers, the mid-level control through interactions that influence the sound, and the high-level, more abstract control in the overall evolutionary process. Many users felt like they didn't have the mid-level control, but users were left feeling in control from both a low-level nature, and a high level.

Overall, users became frustrated when they didn't have an optimal amount of control over a system. Looking at Steuer's [46] model of factors influencing telepresence (seen in Figure 2.2), control falls under the 'interactivity' umbrella, under 'mapping'. From this model, a decreased level of control leads to less telepresence. Dede's [19] model of immersion describes a set of "design strategies that combine actional (actions infeasible, or an extension of real world actions), symbolic (content of experience), and sensory factors". Under this model, lack of control falls under actional factors, as users feel like their actions aren't translating well into the virtual environment.

6.1.1 Hardware Controllers

In general, the feedback surrounding the direct control using the Vive controllers was positive. Users pointed to the controllers feeling very natural, and their actions mostly translated well into the virtual experience. As nothing negative was said around the first-level interaction, I deem this part of the experience successful, and would carry along the same interaction onto any future prototypes. Users also noted they liked the virtual representation of the controllers, stating that they were very clear, and they enjoyed the representation of the feedback — e.g. pushed trigger corresponded to virtual trigger push. An example of this representation can be seen in Figure 3.1.

6.1.2 Agency

Many users explicitly stated they felt like they had minimal agency over the music. Given the feedback from this, upon redesigning the system, I would take into account and draw from existing research on what denotes an 'obvious' parameter change, and interaction. I would then increase the strength of the mapping, increasing telepresence. Many users also pointed to increased visual feedback, especially through shapes or colours, as a means to increase their sense of agency.

6.1.3 Evolutionary Process

Users felt like they were much more in control of the evolutionary process. This level of control is more abstract, as users often described the experience in the sense of guiding a process, rather than

the instruments fitting to them. In general, the instrument sound adjustment seemed to only reduce extremes, rather than producing extremely personalised instruments. However, this may be due to the users only having a limited time with which to interact with the instrument. Therefore, in future tests, I would ask the users to use the system for a longer period. A direct improvement could be leaving a trail of previous instruments, so users can see which instruments they've used. In addition, adding increased use of visual metaphors could be interesting — such as having a virtual 'bin' users throw their unwanted instruments into. This could further reinforce their level of control. Users in general said that incorporating visual feedback into the evolutionary process would take full advantage of the VR, and further reinforce their level of control. This is discussed in more depth later.

6.1.4 Number-based Visual Feedback

Some users gave the example of more explicit visual feedback in the forms of graphs, or changing numbers. This notion would incorporate feedback from the other informational text in the experience, making the text easier to see and more noticeable. Therefore, providing more information (labelled text), or some other sort of diagram could address this problem, and thus provide them with more control. Alternatively another representation could be chosen to convey the evolutionary traits, such as colour, which is explored later.

6.1.5 Control Summary

Moving forward, I would definitely aim to increase the all-round level of control that users have. I would do this through performing more user studies, focusing on specific interactions that are 'sensical' in relation to the music. The example a user describes works well: moving upwards correlating to an increase in pitch. Another essential area for increasing control is increasing visual feedback. With more visual feedback, users can see the results of their actions much more clearly — thus leading to a greater feeling of control. Identifying the correlation between lack of agency and frustration when using, is a key finding throughout this. The way users wanted to control the experience was very much based on their drawing of analogies between the experience and the real world.

6.2 Comparison to Real World

Many users identified parallels between the VR world and how they interacted with the experience. This flavoured their expectations of how the virtual experience would operate, particularly in relation to the sound, and how it operates in the real world. In relation to Steuer's [46] model, many of the real world comparisons would aid in increasing the 'vividness' of the experience, thus increasing telepresence. In particular, as much of the content related directly to the audio, the 'depth' of this input would be increased, and therefore work to increase telepresence.

6.2.1 Types of Sounds Produced

As many users said the space of sounds was limited, on future prototypes I would aim to include and test a larger space of sounds. In general, to inform future design, I think visual representations of the sets of sounds through the space informs the user expectations. As the environment was quite futuristic, I believe this may have influenced the user's expectations for the types of sounds. In future designs, I may A/B test different couples of sounds and scenes, such as a classical orchestral room and conventional instrument sounds. I would also like to explore other, more complex forms of synthesis, such as wavetable, or FM, leading to a larger potential sound space, and therefore greater variation in the possible sounds. As explored in the Contextual Background chapter by Mäki-Petola [41], physical-modelling synthesis could also lend itself to interesting results. The position of the sound was also mentioned frequently.

6.2.2 Spatialisation

Many users referred to their feelings that the audio ought to be coming directly from the instrument itself. This embodiment better represents the real world, in which disembodied audio is a rare occurrence — sounds belong to the interface users are interacting with. This increased layer of audio 'depth' [46] in Steuer's model better represents the real world, and therefore would increase telepresence. Noting that users feel that sound should not be disembodied feeds into general future virtual reality work. Again, using a physical-modelling solution could address this, as described by Mäki-Petola [34].

6.2.3 Comparison to a Conventional Instrument

As little comparison to conventional instruments was found, perhaps the relation was too tenuous, and different levels of abstraction from conventional instruments is needed. Therefore, if I ran another experiment, I would probe further about this, and perhaps include a comparison study with a conventional instrument, such as a guitar, so how a user normally reacts to an instrument in the physical world is fresh in their mind for comparison. As many users overall seemed to discuss conventional musical instruments as much more skill-based and rewarding than my experience, perhaps drawing more from conventional instruments, such as clear cut methods of producing sound (plucking a string) may aid future designs. This works well with Serafin et al.'s [42] design principle number 5: DP5 — natural vs. magical interaction. A balance of both 'magical' and 'natural' interactions is needed.

6.2.3.1 Effect of Previous Experience with Music

Particularly in relation to the types of sounds, the users' previous experience of music seemed to inform their expectations of the experience. Therefore, if I did further user studies I would like to test both on users familiar with listening to and creating synthesised music, and those who aren't.

6.2.4 Other Real World Factors

Other things that users pointed towards were the physical aspects of the VR, such as the gravity being low. Many users felt uncomfortable with the level of gravity, possibly as it felt very unnatural to experience this. This reinforces the earlier idea of finding the balance between natural and magical interactions — magical experiences work better if natural experiences (ones found in the real world) are used as a starting point to build upon, thus increasing immersion.

6.2.5 Comparison to Real World Summary

In general, users had expectations from real world interactions that weren't met by the experience. Implicitly, how we usually interact with interfaces and instruments, and how we expect them to work and sound, shapes our views. However, Virtual Reality does give us the chance to build upon our expectations, and create experiences that augment these expectations. The distinction comes in ensuring that real world expectations aren't completely discarded, but rather used as a base point, to ensure coherency. These improvements all round help improve the 'vividness' from Steuer's [46] model, thus increasing their 'immersion' inside the experience — another key theme.

6.3 Immersion

Many users discussed various factors that led to them feeling immersed in the experience. In general, immersion seemed to be one of the strong positives of the experiment — users felt engaged with the experience. They pointed to Virtual Reality, and its implications, as a key factor in increasing the immersion. As discussed earlier, immersion is best considered in its metaphoric sense, drawing from Murray's [37] definition of immersion as a metaphor: "*derived from the physical experience of being in water. We seek the same feeling . . . the sensation of being surrounded by a completely other reality . . . that takes over all of our attention.*" Virtual Reality offers this, especially when other senses are incorporated, thus increasing the 'breadth' of 'vividness' in Steuer's [46] model.

6.3.1 Tangibility

Many users discussed how they felt that not using any of their 'haptic' sense (as described by Gibson [23]), in the form of vibration, or tactile feedback, was a wasted opportunity. In progressing this project forward, I would aim to incorporate more tactile sensations as a means to increase immersion, by increasing the 'breadth' from Steuer's [46] model.

6.3.2 Feeling of Ownership

One user in particular raised the interesting point of whether a user could feel responsible for the final generation of instrument that was evolved. Users often felt that they were partaking in an experience, but none voiced this negatively, rather they pointed to it as a factor that increased immersion. This wasn't

discussed in depth through the interviews, and therefore in future experiments I would delve deeper into this.

6.3.3 Increased Visual Feedback to Increase Immersion

Users gave explicit recommendations that capitalising more on the potential of VR to feed back into the visual domain in ways that aren't normally possible would increase their sense of immersion, and contribute overall to their experience.

6.3.3.1 Shape-based Visual Feedback

An explicit recommendation I would be extremely keen to use as a basis for future design is using procedural meshes — i.e. each instrument is unique. This mesh could be a function of the genotype, and therefore be considered an extra, more explicit phenotype. Many users described the potential for the shape to be dynamic, so it could match up to the 'sharpness' or 'roundedness' of sounds. However, a few users stated that they enjoyed being able to visualise the sounds for themselves, as they could focus more on the sound. The user who stated they would like increased visual representation of sound identified themselves as a visual learner, and I therefore conclude that this comes down to personal preference. I think it would be extremely interesting to run a comparison on, and collect more information on different sorts of learners, described by Gilakjani [24], such as visual or auditory learners. The unique mesh could also contribute to making the evolutionary process more explicit, as many users stated they felt that the process was too hidden. This was also discussed in a more basic form around the colour of the instruments.

6.3.3.2 Colour-based Visual Feedback

As explored above in describing 'sharp' and 'rounded' sounds, a further user study could be conducted where users are asked which colours best describe different sounds, and then this could be assigned in the generation stage. Another option is that the colour is created as a function of the genome, which would not be hard to implement. I could incorporate both shape and colour for maximum effect.

All the above suggestions point towards adding 'depth' to the 'vividness' of Steuer's [46] model in the visual field. Users in general realised the potential of a VR experience to add super-normal levels of feedback, in comparison to playing with a conventional instrument. Other suggestions point almost towards a synaesthetic experience, where colours and shapes represent sound. Synaesthesia is a neurological condition in which one sensory input may involuntarily overlap onto other sensory inputs [43], resulting in strange phenomena such as tasting shapes or seeing music. This shows a merging of the different senses contributing to the 'breadth' of Steuer's [46] model, which would therefore increase the strength upon the overall telepresence. I believe that VR has a unique potential to offer users a different experience, or interaction, and therefore adding and testing (in an A/B fashion) different levels of visual feedback is one of the most important parts to work on when improving the experience.

6.3.4 Comparison to a Non-VR Interface

Overall, users conclusively pointed towards VR vastly increasing the sense of immersion in the experience in comparison to non-VR interfaces. However, I believe more lessons and ideas can be learnt from existing flat-screen interfaces, especially with DAWs, as they also inform users' expectations.

6.3.5 User-Centric Instrument Choice and 'Flow'

Users pointed towards the experience being enjoyable, and some referred, implicitly and explicitly, to a state of 'flow' that was experienced, particularly due to the Interactive Evolutionary Algorithm.

I believe that in the current age, personalisation will play a key role in user engagement in experiences, especially given the amount of data that can be collected implicitly, and easily in VR. Examples include: time spent looking at an object; movement throughout areas; controller holding pattern; frequency of interaction, and many, many more. These could all be capitalised upon to inform user design, in much the same way that is used very commonly for advertising [11]. However, I believe an in-depth ethical discussion of the ramifications of such an approach would also need to be held, and could be discussed

and analysed in future studies. Modern machine learning technology, such as neural networks, could also play a part in this.

6.3.6 Direct Effect of VR on Immersion

VR technology has progressed vastly in recent years, since it was first created by Ivan Sutherland, who created the first Head-Mounted Display [47]. Wireless controllers, freedom of space, and better graphics all aid in increasing a stronger 'mapping' between user's actions and the virtual space. As Steuer outlines, the smaller the lag between user and action, the more immersed the user becomes. Recent technology such as ultra-haptics [15] and electric stimulation [30] offer exciting new avenues for VR experiences, and I'd like to use these technologies to inform future designs.

6.3.7 Immersion Summary

Overall, many users pointed towards VR increasing their immersion. Most interestingly raised in this area were the improvements that users gave that could help in increasing immersion — some of these were personal to each user, and some were general. In relation to my initial thoughts and hypothesis, I certainly believe that incorporating both Interactive Evolutionary Algorithms and Virtual Reality technology has aided the user immersion in the experience, and in some cases created a state of 'flow'.

6.4 General Usability

Users described some points in relation to their general usability of the experience, mostly small things that would help the experience feel more natural. Many of these are explicitly outlined in Table 5.3. They spanned over many topics including sounds, musical interaction, gravity, calibration, and general enjoyment factors — some more explicit than others. The easier to implement ones, such as "letting users know how many instruments they can use to create their next generation", and "sort out the gravity" would be immediately incorporated into any future designs. The more abstract ones, such as creating a spatial representation of the different parts that make up the whole sound: percussion, synthesis etc. draws parallels from an orchestra. Figuring out different visual representations, or visual metaphors for sound is no easy task, and perhaps would best be considered as part of a separate study.

6.4.1 Informational Text

Another usability factor that was explored was the lack of clarity in the informational text that was displayed in order to guide users through the evolutionary experience. This shows a clear need to readdress the UI of the experience, and users give some ways to address them. Possible other options include adding a 'pop-up' onto the instrument itself, or locking the informational text onto the user's field of view until they dismiss it. There could also be some haptic feedback to reinforce that there would be information the user needed to see. In future experiments I would perhaps trial a few of these ways of presenting information in an A/B test format, and ask users for their feedback.

6.5 Limitations

The only directly addressed limitation in the experiment was the lack of space, which caused users to occasionally knock into the surrounding furniture. To rectify this, I would simply run the same experiment in a bigger space.

The next, and final, chapter presents my conclusions from the study, and my evaluation of the overall project. From these evaluations, some future work is explored.

Chapter 7

Conclusion and Evaluation

7.1 Conclusion

The main aim of my project was to prototype and construct a novel system that incorporated Virtual Reality, Evolutionary Algorithms and Musical Interactions — ultimately to keep users engaged, endlessly fascinated, and progressively shape the instruments to their personal tastes. By these criteria, the project was a success.

As no such system had been designed before, by applying the Research through Design approach, I was also aiming to use this project, and the associated study, to foster new research and reveal insights about how users act in VR with musical interfaces. Several key findings from the study, and resulting discussion were found. Firstly, users were left feeling frustrated when they had a lack of control, which also overall decreased their level of immersion. Ways to increase control include: increasing visual feedback, making interactions more explicit, and adding more obvious feedback from the music. Secondly, users' expectations of VR, taken from analogies with the real world, influenced their immersion. Situations which didn't build upon, or felt unnatural in comparison to, real world interactions led to less immersion. Examples of these are: lack of audio spatialisation, a confined space of instrument sounds, as well as environmental and physical factors, such as gravity. Users also explored other areas by which their immersion was increased, such as directly from the VR system used, and the personalisation produced by the Evolutionary Algorithm. Users pointed towards this creating a state of 'flow'. From this perspective, my hypothesis was proven correct.

In contrast, not capitalising on the full breadth of the users' senses led to less immersion. The tactile system could have been used, with haptic feedback, and the visual system — a core component of VR — could have been used to reinforce the sound. Users were particularly excited by VR's potential to feed into the visual domain, with examples such as increased shape or colour-based feedback. Users also referred to expectations based on the way using the VR was framed: many described it as an experience, and noted that this increased their level of immersion.

Finally, users discussed some general usability factors, such as a need to make the UI more friendly, potentially by drawing more from urban navigation rather than traditional user interfaces. All the above points are useful for creating VR musical interfaces in general, and will help contribute to future research.

7.2 Evaluation of Design using VRMI Principles

As discussed in the Contextual Background chapter, Serafin et al. present 9 principles to evaluate Virtual Reality Musical Instruments. The evaluation of my system using these principles can be seen in Table 7.1.

From this evaluation model, my project certainly has some strengths and weaknesses. Some key weaknesses that could be improved upon are: the presence, body representations, and the social experience factors of the system. However, using the Vive seemed to serve well in many areas, contributing strongly to the ergonomy, low latency, and lack of cyber-sickness. In my system I attempted to be innovative with the technologies and interactions, and this is seen through the natural and magical interactions, and the

VRMI	*DP1: Feedback and mapping*	*DP2: Latency*	*DP3: Cyber Sickness*	*DP4: Do not copy tech.*	*DP5: Interaction Natural / Magic*	*DP6: Ergonomy*	*DP7: Sense of presence*	*DP8: Body represent*	*DP9: Social Experience*
evoVR	AV in tandem	Mentioned, not evaluated (None noted)	Didn't occur during experiments	New techniques	More natural, some magical	Nothing raised about discomfort with Vive	Not explored directly, but through immersion	Virtual representations of controllers	N/A

Table 7.1: Evaluation table of designed system using VRMI design principles by Serafin et al. [42].

'do not copy technology' principles. Overall, the system fared well against this model of evaluation, but points towards areas that could be improved upon.

7.3 Limitations

One of the key limitations upon my project was the small user testing space, and the amount of time the users had to interact with the project. If I were to run this project again, I would aim to run it on a larger demographic, and ask each user to use the experience for a longer amount of time, so that they could properly get to grips with it. I would aim to explore a larger age range, as well as a variety of levels of musical experience. Another limitation discussed previously was the small physical space I had to run my project within. The HTC Vive, and VR in general flourishes when in a big space, so the users can walk around and thus feel more immersed. As the project was also limited to one sort of VR hardware, I'd be interested in testing other VR headsets and controllers, such as the Oculus Rift. However, I consider none of these limitations major, and they in no way severely limited the experiment. I believe that, within the time-frame, what was achieved was a success.

7.4 Future Work

An idea that I'd like to incorporate into future work is the increased visual feedback, as discussed in the previous chapter. I believe procedural meshes, and a study around which meshes work well with which instruments could aid in taking the experience to a new level. Also, increased visual feedback through gestures, UI, and visual metaphors could all be explored. Furthermore, I'd like to incorporate haptic feedback, either in a basic form through the controllers, or perhaps even exploring more state-of-the-art technologies, such as electrical stimulation, which can be used to stimulate muscles to imitate a boundary, or wall. Audio spatialisation and physical-based modelling is another interesting avenue to explore, which could work very well with the VR experience. Machine Learning methods, such as neural networks, also offer an alternative method for increasing personalisation, whereby a user's individual tastes are learnt and used to inform the instrument. A study could be done alongside the existing technology to see which fares better. The Evolutionary Algorithm used in the experiment was very one-dimensional — users could only affect the sound, and not the interaction. In future work I'd like to explore other axes of personalisation, such as interaction and mapping. A personalisation technique that works both explicitly and implicitly could also be trialled, by creating an implicit 'engagement factor' that could detect and quantify how much a user is enjoying a certain instrument.

In terms of the study that was performed, as outlined above, I'd like to perform on a larger demographic, with more participants. The resulting thematic analysis could also be more in-depth, and other methods of analysis could be explored. I believe that qualitative and quantitative analysis would also work well in tandem. VR offers a unique way to collect metrics about how users interact with a system, and much more research into this area is needed.

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Appendix A

Draft NIME poster presentation paper submission

Searching for the Perfect Instrument: A Virtual, Interactive and Evolutionary Experience

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ABSTRACT

In this research study, I introduce and analyse a new Virtual Reality musical interaction system that uses a user-guided evolutionary algorithm to personalise musical instruments to users' individual preferences. The system is designed towards being an 'endlessly entertaining' experience through the potentially infinite number of sounds that can be produced. The hypothesis of the paper was to see if using this trio of technologies augmented a user's immersion levels. I explore surrounding literature, and pull from existing evaluation methodologies to guide and test the system. In addition to this, the system was designed to inform novel research into this unexplored area. After creating this system, a qualitative user study was performed — where users were asked to 'think-aloud' whilst interacting with the system, followed by a Semi-Structured Interview. Thematic analysis was conducted upon the data corpus, in which 5 main themes were found: control, comparison to the real world, immersion, general usability and limitations. In the study, users pointed towards several improvements that would help increase their levels of immersion, such as increased levels of control through augmented visual feedback. It was found overall that this combination of technologies did improve immersion levels, proving the hypothesis to be true.

Author Keywords

Virtual Reality, Evolutionary Algorithms, Adaptable Musical Interface, Qualitative Study

1. INTRODUCTION

I aimed to create a novel musical experience that is an intersection of three existing fields: Virtual Reality, Evolutionary Algorithms and Musical Interaction. Although plenty of research already exists into each field, and even between pairs of each, very limited research has been done with all three. Virtual reality technology still offers many open avenues for users with novel interactions and experiences. The music domain is particularly of interest as creating, or interacting with, music is a challenging, and expressive activity [10]. The open-endedness and subjectivity of the music domain also lends itself to evolutionary algorithms, particularly where a user-centric method is used. This project prototypes an interactive virtual musical system in which a user explores possible musical interactions, and based on their preferences, informs an evolutionary algorithm. I aim to show that the union of these 3 areas increases the overall engagement, and therefore period of time spent, with the experience, and to use the resulting analysis to inform further research.

NIME'18, June 3-6, 2018, Blacksburg, Virginia, USA.

2. MOTIVATION

Music has always had an effect on technological innovation [7], but novel technologies have also led to new musical innovation. The creation of novel musical interfaces helps to inform a new dialogue with music.

Virtual reality offers much potential for new musical expression, surrounding research of which is either quite dated or sparse. Modern technologies have meant that rapid prototyping and testing of virtual environments is very possible. Given the vast space of technologies and interfaces that already exists, personalisation, or user-centric design is gaining popularity [6]. User-centric design means that users can themselves influence the final design of a product, or even create a process of continuous adaptation of interfaces. Evolutionary and Genetic Algorithms offer a potential avenue to explore this in.

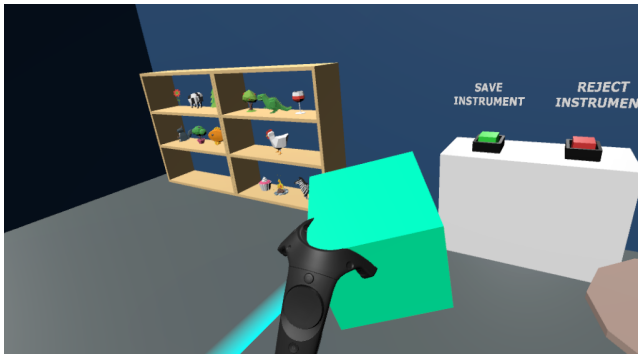

Figure 1: A snapshot of the final system.

3. EXISTING LITERATURE

3.1 VR and Telepresence

The definition of VR as a new medium, consisting of a 'locus of technology' is explored by Steuer [9], and is ultimately dismissed as being inadequate for makers of software for VR, as a definition based purely on the technology does not give any "insights to the processes or effects of the system". He goes on to elaborate on a new definition, involving the notion of telepresence: defined as "the notion of being elsewhere" [1]. The final definition he proposes is a "simulated environment in which a perceiver experiences telepresence". Steuer considers the various factors that help to create a

telepresence, falling under the umbrellas of 'vividness' and 'interactivity'.

3.2 Virtual Reality Musical Instruments

Jaron Lanier [8] first prototyped an 'abstract virtual world' and 3 VR musical instruments in 1987: the 'Rhythm Gimbal' a gyroscopic choral harmony generator; 'CyberXylo', a mallet instrument that maintains angular momentum; and the 'Cybersax' an ergonomically-dynamic instrument [5] - all 3 are designed to harmonise and play together. These instruments highlight some of the things that are possible with Virtual Reality technology. Since 1987, consumer technology has advanced vastly, and in the time, there have been other explorations between virtual reality and musical instruments. Serafin et al. [8] propose a set of design principals for evaluating Virtual Reality Musical Instruments. I will later use these design principles to evaluate my design.

3.3 GAs in the Context of Music

Clearly, unlike some other areas, the music domain does not offer an immediately clear fitness function, however some existing work shows that they may have an application. The work done by Keijzer et al. explores Interactive Evolutionary Algorithms (IEAs) [4], which are named due to their need for a user in the fitness function. Their work is done in the context of learning subjective fitness functions to create 'pleasing' drum patterns. Using a subjective fitness function with evolutionary algorithms, explored in the above papers, as a way for a user to navigate a space of sounds yielded patterns that suited the user more than without a user input. However, personal preference of music and interactions means that what a user deems a successful result may vary vastly dependent on the user and their background.

Despite there being much research individually into the areas explored above, little HCI research exists that engages with the trio of interactive evolutionary algorithms, VR and musical interfaces. Therefore, a qualitative study was undertaken in order to analyse key trends, so they may be pulled out to inform future work.

4. SYSTEM DESIGN

The system was designed using Unity, Pure Data (in the form of LibPD), Virtual Reality Toolkit, and tested using a HTC Vive. An image of the system in action can be seen in Figure 1. In addition, a flow diagram of how the system operates may be seen in Figure 2.

4.1 Musical System and Instrument

The musical system is realised as an exposed Subtractive Synthesizer in Pure Data. It works by taking a sawtooth wave and passing it through a VCF (Voltage Controlled Filter), and then a VCA (Voltage Controlled Amplifier). A VCF shapes an audio wave by specifying start, end and Q (resonance at the cut-off frequency) values. VCFs allow for continuous adjustments of values, which is why they were selected. A VCA adjusts the amplitude of the incoming wave: adjusting it with an ADSR (Attack-Decay-Sustain-Release) envelope that shapes the sound. The parameters to these parts of the system would correspond to a specific 'instrument', along with a specific chosen parameter that would be the controlled parameter from Unity.

I chose that the interaction would not be specifically tied to a user interaction or gesture, but rather that the object's properties would inform the output, and the user would have the freedom to interact with the object in a secondary manner — in the way they saw appropriate. A parallel could be drawn here with conventional instruments, whereby they can often be played in multiple ways, but some ways make more sense than others, or rather more users tend to converge on a specific method of interacting - e.g. plucking guitar strings vs. playing with plectrum vs. using a bow. In the same way, the user was given controllers in order to manipulate the object, and the resulting change in the object's properties would adjust the sound. There are 12 final object properties: the x, y, z components of, and resulting component vectors, translation, rotation and velocity.

4.2 Genome

A metaphor was needed for the representation of an instrument, and since the ultimate aim would be to evolve these instruments, representing them as a genome made the most sense. An example genome can be seen below.

$$\underbrace{1\ 0\ 1}_{\text{control params}} \quad \underbrace{64\ 64\ 64}_{\text{scale, metro, freq}} \quad \underbrace{64\ 64\ 64\ 64}_{\text{env params}} \quad \underbrace{64\ 64\ 64\ 64}_{\text{filter params}}$$

This interwoven system of audio inputs, object parameters, and specific genome structure is the core of the system.

4.3 Evolution

As explored in the supporting material, I concluded that the best way to combine GAs and musical interactions would be with a subjective fitness function, whereby the user specifies their preference for a specific instrument, and this is used to indicate whether an instrument will pass onto the next generation. An implementation of an evolutionary algorithm, consisting of basic crossover and mutation, spawns a new generation of instruments, which are then loaded by the user for use. This process is then repeated.

4.4 Interaction Process

When the player puts on the headset, they see a scene as shown in Figure 1. This includes visualisations of the controllers. A single instrument exists on the table, and the user may interact around and with it as they choose to. When a user passes a controller through the instrument, it changes colour to indicate that the controller is inside. If the user presses the trigger on the back of either controller, while it is held down, the instrument acts as a child of the controller - i.e. it has been grabbed. When the trigger is released the instrument is dropped, but since it acts as a rigid-body it conforms to gravity and maintains any momentum it may have. This allows a user to control the instrument in any way they choose: throwing it up and catching it again, rotating around, waving it around, moving it up and down, holding the object still while physically moving in the space, bouncing it off nearby surfaces, or many other forms of interaction. In addition to this, if the trigger is held before the user inserts the controller into the instrument, and they push against it, the controller acts as a rigid-body, thus allowing a user to push, or nudge the instrument around.

On the left of the user are two buttons, one green, to indicate the saving of the instrument, and one red, which indicates that the user rejects the instrument. These can also be seen in Figure 1. The buttons consist of cubes, that when pressed, trigger the relevant action. The buttons can either be triggered by turning the controller into a rigid-body (by holding the trigger when not in contact with any objects), and pushing downward, or may even be triggered by the instrument itself.

If the save button has been pressed, the genome of the instrument is added to an array of saved genomes. In either case, the current instrument object, and associated script-objects are destroyed. Now, if the evolutionary limit hasn't been reached, a new random genome is generated and pre-

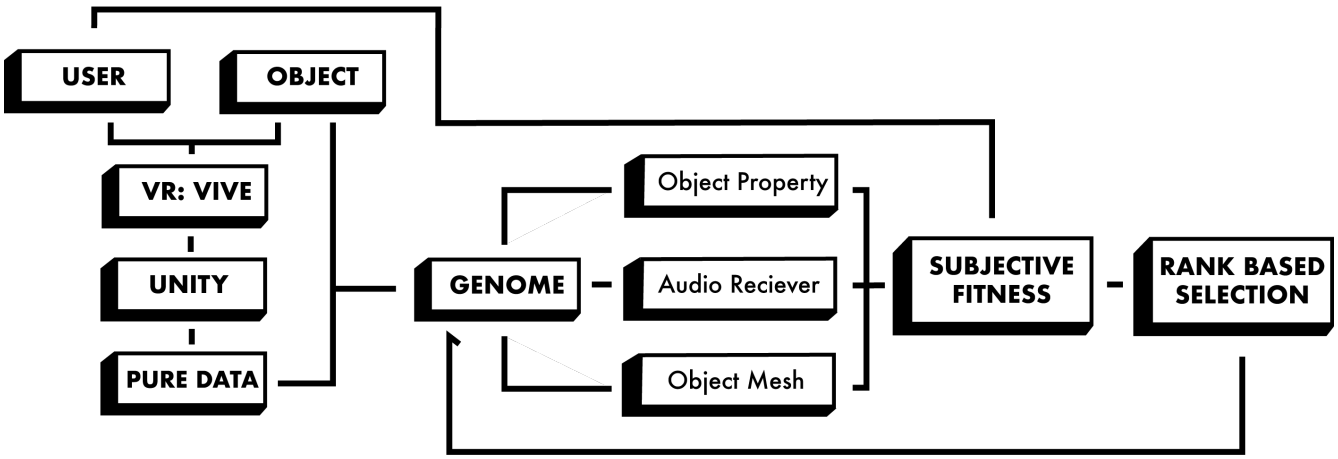

Figure 2: A flow diagram of the system logic.

sented to the user, in the same way as above. A new instrument rigid-body object is generated on the table, for the user to interact with. If the evolutionary limit has been reached, the evolutionary process starts. In all cases, text appears for 5 seconds above the buttons, indicating what action has been taken.

The genome is mutated with a crossover algorithm, and the users are presented with an instrument loaded from the next generation. The user may then specify their preferences, and the cycle repeats.

5. EXPERIMENTAL DESIGN

With a basic prototype completed, the next stage was to perform experiments in which users are asked to interact with the system, and their responses are recorded, transcribed, and analysed for recurring themes. The PRET A Rapporter framework (PRETAR) described by Blandford [2] gives a basic structure for designing, undertaking and reporting Semi-Structured Qualitative Studies (SSQSs).

5.1 Participants

As well as performing the interviews, I collected some minimal background data on the participants, asking their age, gender, musical and VR experience, in order to try and minimize any external factors that may influence the outcome of the experiment. This simple questionnaire contained questions with a simple scale, where the meaning of each of the responses was clearly indicated above. The experiments were run across one week. In total, there were 6 participants, with resulting audio spanning between 15-20 minutes for each. Therefore, approximately 90 minutes of audio data was collected and transcribed during the study.

Subject ID	Age	Gender	Musical Experience (ME)	VR Experience (VRE)	Pseudonym
VR01	22	F	3	3	Annie
VR02	22	M	4	4	Bob
VR03	22	M	2	5	Carl
VR04	21	M	2	4	Dylan
VR05	21	F	3	3	Eva
VR06	26	F	3	4	Flo

Table 1: A table of the participants of the experiments, and their collected demographic data.

5.2 Data Collection

Users were given very simple instructions, and then asked to partake in the experience for around 15 minutes. As part of the information sheet, the users were instructed that they would need to 'think-aloud'. The 'think-aloud' vocalisation would happen whilst users were inside the experience, giving them the chance to relay any thoughts they may not remember or picked up on once they had stopped engaging with the experience. After this, the users took part in a Semi-Structured Interview, where there would be a rough topic guide.

6. DATA ANALYSIS

Thematic analysis is described by Guest [3] as a technique of analysing qualitative data through the targeting of recurring themes in data. This was performed upon, via the coding process, the transcribed data corpus from the study.

7. RESULTS

In the following section I present the themes that arose whilst conducting the thematic analysis. During the process, 5 key themes arose: Control, Comparison to Real World, Immersion, General Usability, and Limitations.

7.1 Control

Throughout the experiments, users referred to their feelings surrounding levels of control. In the experience, there were 3 main levels in which control could be exerted: The low-level direct control through the hardware controllers, the mid-level control through interactions that influence the sound, and the high-level, more abstract control in the overall evolutionary process. Many users felt like they didn't have the mid-level control, but users were left feeling in control from both a low-level nature, and a high level.

Overall, users became frustrated when they didn't have an optimal amount of control over a system. Looking at Steuer's [9] model of factors influencing telepresence, control falls under the 'interactivity' umbrella, under 'mapping'. From this model, a decreased level of control leads to less telepresence.

7.2 Analogies with Real World

Many users identified parallels between the VR world and how they interacted with the experience. This flavoured

their expectations of how the virtual experience would operate, particularly in relation to the sound, and how it operates in the real world.

7.3 Immersion

Many users discussed various factors that led to them feeling immersed in the experience. In general, immersion seemed to be one of the strong positives of the experiment - users felt engaged with the experience. They pointed to Virtual Reality, and its implications, as a key factor in increasing the immersion. Virtual Reality offers this, especially when other senses are incorporated, thus increasing the 'breadth' of 'vividness' in Steuer's [9] model.

8. EVALUATION

The main aim of my project was to prototype and construct a novel system that incorporated Virtual Reality, Evolutionary Algorithms and Musical Interactions — ultimately to keep users engaged, endlessly fascinated, and progressively shape the instruments to their personal tastes. By this criteria, the project was a success.

Several key findings from the study, and resulting discussion were found. Firstly, users were left feeling frustrated when they had a lack of control, which also overall decreased their level of immersion. Ways to increase control include: increasing visual feedback, making interactions more explicit, and adding more obvious feedback from the music. Secondly, users' expectations of VR, taken from analogies with the real world, influenced their immersion. Situations which didn't build upon, or felt unnatural in comparison to, real world interactions led to less immersion. Examples of these are: lack of audio spatialisation, a confined space of instrument sounds, as well as environmental and physical factors, such as gravity. Users also explored other areas by which their immersion was increased, such as directly from the VR system used, and the personalisation produced by the Evolutionary Algorithm. Users pointed towards this creating a state of 'flow'.

In contrast, not capitalising on the full breadth of the users' senses led to less immersion. The tactile system could have been used, with haptic feedback, and the visual system - a core component of VR - could have been used to reinforce the sound. Users were particularly excited by VR's potential to feed into the visual domain, with examples such as increased shape or colour-based feedback. Users also referred to expectations based on the way using the VR was framed: many described it as an experience, and noted that this increased their level of immersion.

Finally, users discussed some general usability factors, such as a need to make the UI more friendly, potentially by drawing more from urban navigation rather than traditional user interfaces. All of the above points are useful for creating VR musical interfaces in general, and will help contribute to future research.

9. EVALUATION OF DESIGN USING VRMI PRINCIPLES

As discussed earlier, Serafin et al. present 9 principles to evaluate Virtual Reality Musical Instruments. The evaluation of my system using these principles can be seen in Table 2.

From this evaluation model, my project certainly has some strengths and weaknesses. Some key weaknesses that could be improved upon are: the presence, body representations, and the social experience factors of the system. However, using the Vive seemed to serve well in many areas, contributing strongly to the ergonomy, low latency, and lack

VRMI	*DP1: Feedback and mapping*	*DP2: Latency*	*DP3: Cyber Sickness*	*DP4: Do not copy tech.*	*DP5: Interaction Natural / Magic*	*DP6: Ergonomy*	*DP7: Sense of presence*	*DP8: Body represent*	*DP9: Social Experience*
evoVR	AV in tandem	Mentioned, not evaluated (None noted)	Didn't occur during experiments	New techniques	More natural, some magical	Nothing raised about discomfort with Vive	Not explored directly, but through immersion	Virtual representations of controllers	N/A

Table 2: Evaluation table of designed system using VRMI design principles by Serafin et al. [8].

of cyber-sickness. In my system I attempted to be innovative with the technologies and interactions, and this is seen through the natural and magical interactions, and the 'do not copy technology' principles. Overall, the system fared well against this model of evaluation, but points towards areas that could be improved upon.

10. FUTURE WORK

Procedural meshes provide an interesting exploration point, and a study around which meshes work well with which instruments could aid in taking the experience to a new level. Also, increased visual feedback through gestures, UI, and visual metaphors could all be explored. Furthermore, I'd like to incorporate haptic feedback, as well as audio spatialisation and physical-based modelling. Machine Learning methods, such as neural networks, also offer an alternative method for increasing personalisation. The Evolutionary Algorithm used in the experiment was very one-dimensional - users could only affect the sound, and not the interaction. In future work I'd like to explore other axes of personalisation, such as interaction and mapping. A personalisation technique that works both explicitly and implicitly could also be trialled, by creating an implicit 'engagement factor' that could detect and quantify how much a user is enjoying a certain instrument.

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Appendix B

Code Snippets

B.1 Evolutionary Code

```
// implementation of the crossover algorithm
       public void crossover(List<List<int>> mother, List<List<int>> father, List<List
           ↪ <List<int>>> children) {

               var child1 = new List<List<int>> ();
               var child2 = new List<List<int>> ();

               child1.Add (mother [0]);
               child1.Add (mother [1]);
               child1.Add (father [2]);
               child1.Add (father [3]);

               child2.Add (father [0]);
               child2.Add (father [1]);
               child2.Add (mother [2]);
               child2.Add (mother [3]);


               children.Add (child1);
               children.Add (child2);

       }


}

       public List<List<List<int>>> mutate_genome() {

               Debug.Log ("Genomes are being mutated");

               var children = new List<List<List<int>>> ();

//  foreach (List<int> genome in saved_genomes) {
//   condensed_list.AddRange (genome);
//  }

               int genome_length = saved_genomes.Count;

//  Combinations genome_combinations = new Combinations(saved_genomes, 2);

               if (genome_length % 2 == 0) {
```

```
                    for (int i = 0; i <= ((genome_length - 1) / 2); i += 2) {
                        crossover (saved_genomes [i], saved_genomes [i+1],
                            ↪ children);

                    }

                }

                else {

//   wrap around so first is paired with last initially

                    crossover(saved_genomes[0], saved_genomes[genome_length - 1],
                        ↪ children);

                    for (int i = 0; i <= ((genome_length - 1) / 2); i += 2) {
                        crossover (saved_genomes [i], saved_genomes [i+1],
                            ↪ children);

                    }
                }

                return children;


        }
```

B.1.1 Genome Code

```
        // make a new genome, randomise all parameters
        public void new_genome() {

                if (debug) {

                    env_gen [0] = 0;
                    env_gen [1] = 30;
                    env_gen [2] = 64;
                    env_gen [3] = 30;

                    filter_gen [0] = 64;
                    filter_gen [1] = 64;
                    filter_gen [2] = 10;
                    filter_gen [3] = 0;

                    metro_gen [0] = 9;
                    metro_gen [1] = 64;
                    metro_gen [2] = 64;



                } else {

                    for (int i = 0; i < env_gen.Length; i++) {
                        env_gen [i] = Random.Range (1, 127);
                    }
```

```
                for (int i = 0; i < filter_gen.Length; i++) {
                        filter_gen [i] = Random.Range (1, 127);
                }

                for (int i = 0; i < metro_gen.Length; i++) {
                        metro_gen [i] = Random.Range (1, 127);
                }

                metro_env_filter = Random.Range (0, 2);

                if (metro_env_filter == 0) {
                        receiver_index = Random.Range (0, metro_gen.Length);
                } else {
                        receiver_index = Random.Range (0, filter_gen.Length);
                }

                if (metro_env_filter == 0 && receiver_index == 2) {
                        metro_on = 0;
                }

                //   for now cap q value as lower due to lack of sound issues

                env_gen [3] = env_gen [3] % 64;

                rb_property_index = Random.Range (0, rb_prop_length);

        }
    }

// for loading a genome
    public Genome(Rigidbody r, List<int> subdna1, List<int> subdna2, List<int>
        ↪ subdna3, List<int> subdna4) {
        Debug.Log ("genome sucessfully loaded");


        rb = r;
        get_rb_properties ();

        sound_receives = new string[4][];
        sound_receives[0] = metro;
        sound_receives[1] = env;
        sound_receives[2] = filter;

        metro_env_filter = subdna1 [0];
        receiver_index = subdna1 [1];
        rb_property_index = subdna1 [2];

        env_gen = subdna2.ToArray ();
        filter_gen = subdna3.ToArray ();
        metro_gen = subdna4.ToArray ();

    }

        public List<List<int>> genome_to_list() {
        List<List<int>> dna = new List<List<int>> ();

        List<int> subdna = new List<int> ();
```

```
            Debug.Log (subdna);
            Debug.Log(current_genome);
            subdna.Add (current_genome.metro_env_filter);
            subdna.Add (current_genome.receiver_index);
            subdna.Add (current_genome.rb_property_index);

            dna.Add (subdna);

            List<int> subdna2 = new List<int> ();
            subdna2.AddRange (current_genome.env_gen);
            dna.Add (subdna2);

            List<int> subdna3 = new List<int> ();
            subdna3.AddRange (current_genome.filter_gen);
            dna.Add (subdna3);

            List<int> subdna4 = new List<int> ();
            subdna4.AddRange (current_genome.metro_gen);
            dna.Add (subdna4);

            return dna;
        }

        public List<List<int>> random_genome() {
            List<List<int>> dna = new List<List<int>> ();

            List<int> subdna = new List<int> ();

            Genome random_genome = new Genome ();

            subdna.Add (random_genome.metro_env_filter);
            subdna.Add (random_genome.receiver_index);
            subdna.Add (random_genome.rb_property_index);

            dna.Add (subdna);

            List<int> subdna2 = new List<int> ();
            subdna2.AddRange (random_genome.env_gen);
            dna.Add (subdna2);

            List<int> subdna3 = new List<int> ();
            subdna3.AddRange (random_genome.filter_gen);
            dna.Add (subdna3);

            List<int> subdna4 = new List<int> ();
            subdna4.AddRange (random_genome.metro_gen);
            dna.Add (subdna4);

            return dna;
        }
```

B.2 Instrument Code

```
        // create a new instrument with a new genome if the number of instruments is
            ↪ below a threshold
        public void new_instrument() {
```

```
            Debug.Log("Making a new instrument!");

//  for now, always destroy the last instrument
            destroy_instrument();

//  check if it's the first generation, and then if so, don't load any genomes
            if (generation == 1) {

//   check the number of saved is <= to the threshold for next generation
//   if so make new instrument


                    if (saved_genomes.Count <= count_before_evolution) {

                            gui_text.enable_text ("New instrument made!");

                            inst = Instantiate (inst_prefab);

                            inst.GetComponent <MeshRenderer> ().material.color = new
                                ↪ Color (Random.Range (0f, 1f), Random.Range (0f, 1f)
                                ↪ , Random.Range (0f, 1f), Random.Range (0f, 1f));

                            instrument = inst.GetComponent<Rigidbody> ();

//    Genome gen = new Genome (instrument);
//    lib_control = new LibControl (instrument, gen);

                            lib_control = inst.AddComponent<LibControl> ();

                            current_genome = lib_control.get_genome ();
//    instrument_number += 1;

//   otherwise if the number of instruments has surpassed threshold
//   need to assign saved genomes to other List, and load first genome
                    } else {


                            //   mutate_genome ();
                            generation = generation + 1;
                            child_index = 0;

                            gui_text.enable_text ("Generation: " + generation + ".
                                ↪ Genome mutated.");

                            Debug.Log ("Generation: " + generation);

                            genomes_to_load = mutate_genome ();

//    blank out saved genomes, so that can assign new genomes to it
                            saved_genomes = new List<List<List<int>>> ();

                            load_genome (genomes_to_load, child_index);
                            child_index++;

                    }


//  otherwise the genome needs to be loaded from the mutated list
```

```
            } else {

                    //   check if limit has been received, and if not, we're just
                        ↪ loading the next instrument
                    if (child_index < genomes_to_load.Count) {

                            gui_text.enable_text ("instrument number " + child_index
                                ↪ + "loaded.");


                            load_genome (genomes_to_load, child_index);
                            child_index++;
                    }

//   otherwise we need to move on to another generation
//   for now this just happens when all the mutated instruments have been tested
//   but could potentially add some random instruments in there, just test and see
    ↪ perhaps.
                    else {

                            generation++;

                            Debug.Log ("Generation: " + generation);

                            child_index = 0;

                            genomes_to_load = mutate_genome ();

//    blank out saved genomes, so that can assign new genomes to it
                            saved_genomes = new List<List<List<int>>> ();

                            load_genome (genomes_to_load, child_index);
                            child_index++;
                    }
            }

       }
```

Appendix C

Pure Data Patch

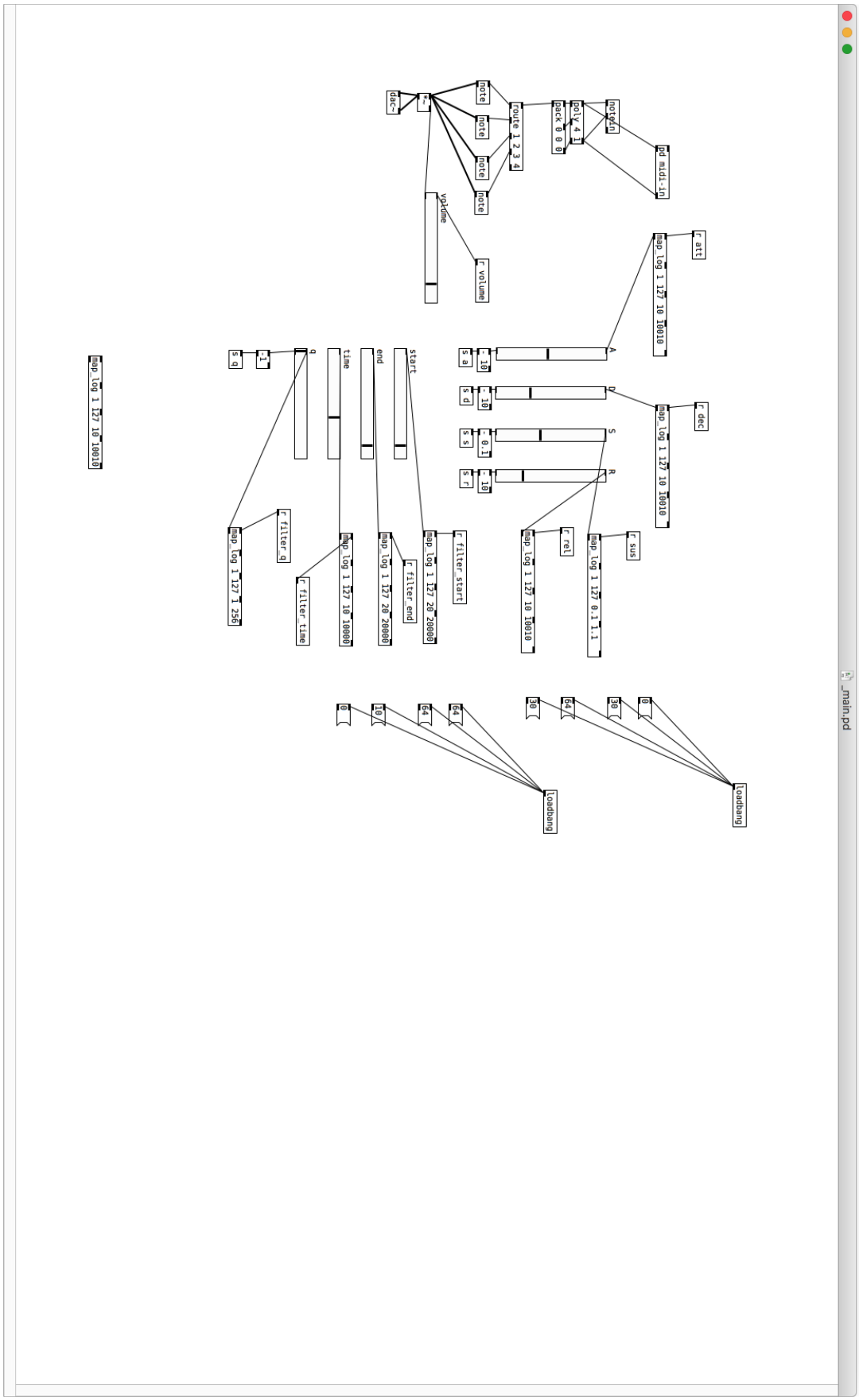

Figure C.1: A snapshot of the main Pure Data Patch.

Appendix D

Experiment Documents

D.1 Information Sheet

Dhruv Chauhan
Undergraduate MEng Computer Science
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E: dc14690@my.bristol.ac.uk
T: 07915984907

University of BRISTOL

Information Sheet

Research Study: Evolutionary Musical Interactions in VR: An Exploratory Study

I would like to invite you to take part in this research project. Participation is entirely at your discretion, if you decide at any point that you would not like to participate, there with be no disadvantage, and you may stop whenever. Please read the following information carefully before you decide to take part. If you would like any clarification of anything stated in this document, or any further information, please do not hesitate to ask. If you decide to participate, you will be asked to sign a consent form. Even after this has happened, you are free to withdraw from the study at any point in time.

In this study, I would like to hear about your thoughts, feelings and reactions regarding the new *evolutionary musical interaction* system I am developing. This consists of interacting with an object using a Virtual Reality (HTC Vive) headset, and controller(s). You will be asked a few basic questions before using the system, and you will be asked to express yourself whilst using the VR system. Finally, a few follow-up questions will be asked. Overall, the whole process should take approximately 15 minutes.

If you consent to taking part in the study, you agree that I may record the audio of our experience, so that I may analyse your responses to the system, before, during and afterwards. This data will be stored in a confidential form and anonymised so that it cannot be used to identify you.

This project is being run as a final MEng Computer Science project by Dhruv Chauhan. If you would like to get in touch about the project, you can contact me at dc14690@my.bristol.ac.uk.

D.2 Participant Questionnaire

Dhruv Chauhan
Undergraduate MEng Computer Science
MVB, Woodland Road, BS8 1UB
E: dc14690@my.bristol.ac.uk
T: 07915984907

University of BRISTOL

SUBJECT ID		**AUDIO ID**	
DATE			

Pre-Experiment Questions

Evolutionary Musical Interactions in VR: An Exploratory Study

Dhruv Chauhan, MEng Computer Science

Supervisor:
Dr Pete Bennett

Ethics Approval Code:

65421

General Questions

Please tick the circles as appropriate.

1) What is your gender?

○ Female	○ Male	○ Other

2) What is your age?

My age is….	_____

3) How would you describe your VR experience? Please circle accordingly.

1) No experience at all.
2) Heard about VR technology.
3) Used once before (demo, friends etc.).
4) Used multiple times, in different contexts.
5) Own a VR headset.

1	2	3	4	5

4) How would you describe your musical experience?

1) No experience at all.
2) Like listening to music, but don't play any instruments.
3) Play an instrument / produce / DJ (etc.).
4) Play more than one instrument.
5) Professional player / master of several instruments.

1	2	3	4	5

D.3 Semi-structured Interview Topic Guide

Dhruv Chauhan
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University of BRISTOL

Topic Guide

Research Study: Evolutionary Musical Interactions in VR: An Exploratory Study

During Experiment:

Can you voice any thoughts you have whilst using the system, and about how you find interacting with it?

Detailed instructions for how to think aloud should be given: "Encourage the participant to speak constantly 'as if alone in the room' without regard for coherency." Participants should have a chance to practice thinking aloud prior to the study.

After Experiment:

- *So what did you think was happening?*
- *What were your first impressions? (Did these shift as you spent longer inside the experience?)*
- *What did you think of interacting with the instrument?*
- *How easy was it to use?*
- *How does this compare to using a conventional instrument? (How does it compare with a physical instrument / object?)*
- *How does the VR experience compare to a non-VR experience?*
- *Is there anything you would add to the experience?*

D.4 Participant Consent Form

Dhruv Chauhan
Department of Computer Science
T: 07915984907
E: dc14690@my.bristol.ac.uk

University of BRISTOL

CONSENT FORM
Evolutionary Musical Interactions in VR: An Exploratory Study

Please answer the following questions to the best of your knowledge

	YES	NO
DO YOU CONFIRM THAT YOU:		
• Understand that you will need to use a VR Headset and Controllers?	☐	☐
• our conversation and your responses will be audio-recorded?	☐	☐
HAVE YOU:		
• been given information explaining about the study?	☐	☐
• had an opportunity to ask questions and discuss this study?	☐	☐
• received satisfactory answers to all questions you asked?	☐	☐
• received enough information about the study for you to make a decision about your participation?	☐	☐
DO YOU UNDERSTAND:		
that you are free to withdraw from the study and free to withdraw your data prior to final consent		
• at any time?	☐	☐
• without having to give a reason for withdrawing?	☐	☐

I hereby fully and freely consent to my participation in this study

I understand the nature and purpose of the procedures involved in this study. These have been communicated to me on the information sheet accompanying this form.
I understand and acknowledge that the investigation is designed to promote scientific knowledge and that the University of Bristol will use the data I provide for no purpose other than research.
I understand that the data I provide will be kept **confidential**, and that on completion of the study my data will be **anonymised** by removing all links between my name or other identifying information and my study data. This will be done by 04/05/18, and before any presentation or publication of my data.
I understand that the University of Bristol may use the data collected for this project in a future research project but that the conditions on this form under which I have provided the data will still apply.

Participant's signature: _____ Date: _____

Name in BLOCK Letters: _____

Final consent
Having participated in this study

I agree to the University of Bristol keeping and processing the data I have provided during the course of this study. I understand that these data will be used only for the purpose(s) set out in the information sheet, and my consent is conditional upon the University complying with its duties and obligations under the Data Protection Act.

Participant's signature: _____ Date: _____

Name in BLOCK Letters: _____

If you have any concerns related to your participation in this study please direct them to the Faculty of Science Human Research Ethics Committee, via Liam McKervey, Research Ethics Co-ordinator (Tel: 0117 928 7841 email: Liam.McKervey@bristol.ac.uk).

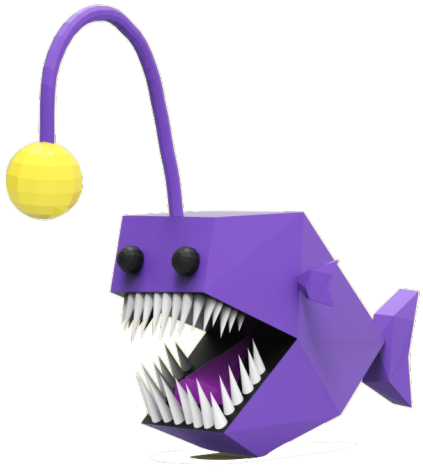
D.5 Experiment Poster

VOLUNTEERS NEEDED!

15 MINUTE VR MUSIC INTERACTION EXPERIMENT

HTC VIVE HEADSET

COOKIE-BASED REIMBURSEMENT



Appendix E

Experiment Questionnaires

Dhruv Chauhan
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E: dc14690@my.bristol.ac.uk
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University of BRISTOL

SUBJECT ID	01	AUDIO ID	01
DATE	07/04/18		

Pre-Experiment Questions

Evolutionary Musical Interactions in VR: An Exploratory Study

Dhruv Chauhan, MEng Computer Science

Supervisor:
Dr Pete Bennett

Ethics Approval Code:

General Questions

Please tick the circles as appropriate.

1) What is your gender?

○ Female	○ Male	○ Other

2) What is your age?

My age is….	12

3) How would you describe your VR experience? Please circle accordingly.

1) No experience at all.
2) Heard about VR technology.
3) Used once before (demo, friends etc.).
4) Used multiple times, in different contexts.
5) Own a VR headset.

1	2	(3)	4	5

4) How would you describe your musical experience?

1) No experience at all.
2) Like listening to music, but don't play any instruments.
3) Play an instrument / produce / DJ (etc.).
4) Play more than one instrument.
5) Professional player / master of several instruments.

1	2	(3)	4	5

Dhruv Chauhan
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University of BRISTOL

SUBJECT ID	02	**AUDIO ID**	02
DATE	07/04/18		

Pre-Experiment Questions

Evolutionary Musical Interactions in VR: An Exploratory Study

Dhruv Chauhan, MEng Computer Science

Supervisor:
Dr Pete Bennett

Ethics Approval Code:

General Questions

Please tick the circles as appropriate.

1) What is your gender?

O Female	✓ Male	O Other

2) What is your age?

My age is....	22

3) How would you describe your VR experience? Please circle accordingly.

1) No experience at all.
2) Heard about VR technology.
3) Used once before (demo, friends etc.).
4) Used multiple times, in different contexts.
5) Own a VR headset.

1	2	3	(4)	5

4) How would you describe your musical experience?

1) No experience at all.
2) Like listening to music, but don't play any instruments.
3) Play an instrument / produce / DJ (etc.).
4) Play more than one instrument.
5) Professional player / master of several instruments.

1	2	3	(4)	5

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University of BRISTOL

SUBJECT ID	03	**AUDIO ID**	03
DATE			

Pre-Experiment Questions

Evolutionary Musical Interactions in VR: An Exploratory Study

Dhruv Chauhan, MEng Computer Science

Supervisor:
Dr Pete Bennett

Ethics Approval Code:

General Questions

Please tick the circles as appropriate.

1) What is your gender?

O Female	✓ Male	O Other

2) What is your age?

My age is….	22

3) How would you describe your VR experience? Please circle accordingly.

1) No experience at all.
2) Heard about VR technology.
3) Used once before (demo, friends etc.).
4) Used multiple times, in different contexts.
5) Own a VR headset.

1	2	3	4	(5)

4) How would you describe your musical experience?

1) No experience at all.
2) Like listening to music, but don't play any instruments.
3) Play an instrument / produce / DJ (etc.).
4) Play more than one instrument.
5) Professional player / master of several instruments.

1	(2)	3	4	5

Dhruv Chauhan
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University of BRISTOL

SUBJECT ID	04	AUDIO ID	04
DATE	09/04/18		

Pre-Experiment Questions

Evolutionary Musical Interactions in VR: An Exploratory Study

Dhruv Chauhan, MEng Computer Science

Supervisor:
Dr Pete Bennett

Ethics Approval Code:

General Questions

Please tick the circles as appropriate.

1) What is your gender?

O Female	⊙ Male	O Other

2) What is your age?

My age is....	21

3) How would you describe your VR experience? Please circle accordingly.

1) No experience at all.
2) Heard about VR technology.
3) Used once before (demo, friends etc.).
4) Used multiple times, in different contexts.
5) Own a VR headset.

1	2	3	(4)	5

4) How would you describe your musical experience?

1) No experience at all.
2) Like listening to music, but don't play any instruments.
3) Play an instrument / produce / DJ (etc.).
4) Play more than one instrument.
5) Professional player / master of several instruments.

1	(2)	3	4	5

Dhruv Chauhan
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University of BRISTOL

SUBJECT ID	05	**AUDIO ID**	05
DATE	09/04/18		

Pre-Experiment Questions

Evolutionary Musical Interactions in VR: An Exploratory Study

Dhruv Chauhan, MEng Computer Science

Supervisor:
Dr Pete Bennett

Ethics Approval Code:

General Questions

Please tick the circles as appropriate.

1) What is your gender?

⊙ Female	O Male	O Other

2) What is your age?

My age is....	21

3) How would you describe your VR experience? Please circle accordingly.

1) No experience at all.
2) Heard about VR technology.
3) Used once before (demo, friends etc.).
4) Used multiple times, in different contexts.
5) Own a VR headset.

1	2	(3)	4	5

4) How would you describe your musical experience?

1) No experience at all.
2) Like listening to music, but don't play any instruments.
3) Play an instrument / produce / DJ (etc.).
4) Play more than one instrument.
5) Professional player / master of several instruments.

1	2	(3)	4	5

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University of BRISTOL

SUBJECT ID	06	AUDIO ID	06
DATE	09/04/18		

Pre-Experiment Questions

Evolutionary Musical Interactions in VR: An Exploratory Study

Dhruv Chauhan, MEng Computer Science

Supervisor:
Dr Pete Bennett

Ethics Approval Code:

General Questions

Please tick the circles as appropriate.

1) What is your gender?

☑ Female	○ Male	○ Other

2) What is your age?

My age is....	26

3) How would you describe your VR experience? Please circle accordingly.

1) No experience at all.
2) Heard about VR technology.
3) Used once before (demo, friends etc.).
4) Used multiple times, in different contexts.
5) Own a VR headset.

1	2	3	(4)	5

4) How would you describe your musical experience?

1) No experience at all.
2) Like listening to music, but don't play any instruments.
3) Play an instrument / produce / DJ (etc.).
4) Play more than one instrument.
5) Professional player / master of several instruments.

1	2	(3)	4	5

Appendix F

Full Transcripts

F.1 VR01

F.1.1 Think-Aloud

S: Is it this red cube?

D: Yep

S: Oh! ... There's not that much sound. Oh!

D: Oh yeah don't worry about getting it, maybe get a new instrument?

S: *laughs*

D: If you can't pick it up, don't worry. Just get...

S: No I'm just... is it supposed to make a noise when I ... when I'm picking it up? Can you turn up the volume please?

D: Yeah, of course.

S: That's so cool.

D: Remember, try and say what you're thinking

S: Is it ... Is it supposed to make a noise when I throw it?

D: It's just supposed to change somehow.

S: OK. I don't really like this one.

D: What are you thinking?

S: Um... Ooh I like that one. I like how it moves. Ok, I'm not gonna get that one. I'm gonna accept that one. Oh no, sorry did I... press it twice?

D: It's ok.

S: This sounds like when you play with the ... keyboard in GCSE music.

D: Try to be vocal about it, if you can.

S: Ok.

D: How are you finding everything in general?

S: The cu... the way the cube moves is really fun.

D: Ok.

S: Come back... It's like a balloon, I really like it.

D: What about the sound?

S: I don't really like it that much. But it's Ok. It sounds a bit like an organ.

S: *sound changes* oh this is a horrible one. No, I don't like this.

D: Try and say what you're thinking about.

S: I'm not really thinking anything, I'm just playing with it.

D: How are you finding using the controllers? Or the general experience?

S: Yeah, it's quite easy. It's quite weird though, because I haven't really done anything like this. I can't really hear anything to be honest.

D: Ok. So you think it could be louder?

S: That one - yeah I can't hear it.

D: Ok. Thanks, that's alright. Why don't you try throwing it up and catching it again?

S: Ok. Ooh. Bye. Ooh, that was funny *laughs*. I like that. Come back! No!

D: I think you'll have to try a gentler throw.

S: Ok. No. That was so cool - I can't believe you can do that. It feels very real. I mean I know it's virtual reality, but.

D: So the numbers on the wall in front of you represent the ... can you see the numbers on the wall?

bang

D: Watch out. Can you see the numbers? That's the unique genome of the instrument you're playing each time. After you've pressed save 4 times, it should start to load them, using bits you like of your choices.

S: Ok. Oh cool.

D: ... instrument number... So now it's loaded an instrument. So some bit of the instrument before that you were using has been...

S: I keep wanting to put it to my ear. I don't know why.

D: Ok. That's interesting. Do you want to say some more about that?

S: Well... I hear the noise, but I feel like it's coming from the cube, but I ... so I want to hear it properly, because it's quite quiet.

D: Ok. Would you rather have it through headphones?

S: Yeah, possibly. It's fine, but if we're basing it on whether I like it or not ...

D: And I presume you'd like to have a bigger space to move around in?

S: Yeah. When it falls there, I'd like to go after it.

D: Ok.

S: If that's ok.

bang

D: It's not gonna happen, I think leave it.

S: Ok. *laughs*.

S: This one's silent.

D: Ok. Well, maybe just move on.

S: Is that OK?

D: Yeah.

new instrument.

D: What do you think about this one?

S: I like this one.

D: Have you tried hitting the buttons with the cube?

S: Hitting what?

D: You can hit the buttons with the cube.

S: Did that work? Oh!

D: How do you feel about how the new instrument's appear?

S: Yeah good! They just, come.

D: Does that seem to make sense?

S: Yeah! Well you know they're gonna be there. On the table.

D: Do you wish you could see your previous instru...

S: I find it quite weird that table's not there. Do you wish what?

D: If you press the trigger, and push through the table, it'll resist.

S: Yeah. What the cube will?

D: No, if you let go of the cube.

S: Ooh! What were you gonna ask before? How do you feel about?

D: Ok - do you want to stop? And I can ask you some questions.

S: Yeah.

D: Ok.

F.1.2 Semi-Structured Interview

D: I'm gonna ask you some questions now, and if possible can you try and talk about them as clearly as possible. But just generally say what you're thinking.

S: Ok.

D: So ... what did you think was happening?

S: Um... I'm not really sure... because... I think the sound was changing, but then sometimes when you got a new instrument, the sound didn't change.

D: Ok, so you felt like you were doing things and...

S: It changed like every like 2 instruments... I don't know.

D: Ok. So you couldn't find any, kind of, coherency?

S: No.... I think... yeah.

D: Ok. Anything more to say on that?

S: Um... well I know that when you accepted one it was making it more like that, sound you accepted.

D: Could you tell that? Or were you just thinking that?

S: I was just thinking it, really. I couldn't ... yeah ... I dunno. I thought what was gonna happen was there was gonna be one instrument at the end that's an accumulation of all those ones you accepted. I actually didn't realise it was doing it as you go. Is that what was happening?

D: Would you rather have that? Than the thing you used?

S: Uuh... No, I think the thing is cool, I just didn't ...

D: So you'd like to know what's going on in more detail?

S: Yeah. But it might have just been me not listening.

D: What were your first impressions?

S: Yeah, I thought it was cool. I thought it was gonna be harder to use, than it is.

D: So fairly easy to use?

S: When you explained it I was ... The best way for me to do it is to just ... do it.

D: Have a go...

S: Yeah, have a practice.

D: Did these change as you spent longer inside?

S: Did what?

D: Did these... your impressions change as you spent longer inside?

S: Yeah... probably.

D: In what way?

S: I dunno, I just got, I felt like I could use it. Like play with it a bit more.

D: Ok. Playful?

S: Yeah. And, I could.... um... Yeah... I dunno. I felt like I could... yeah.

D: Uh, what did you think of interacting with the instrument?

S: Yeah, it was good. But I thought that when you threw it, it was gonna change the sound.

D: And you felt like it wasn't, sometimes?

S: I didn't think it was. I thought when you threw it it was gonna get louder, or something, when it hit the wall.

D: So the changes aren't obvious enough?

S: I personally... I didn't really notice them that much.

D: So how it works is ... your cube has random parameters. It has rotation, orientation, or its speed. And those get mapped onto random parameters on the sound.

S: So it changes.

D: It changes, but sometimes the co-ordination of those aren't necessarily that obvious. So it could be that for some reason the sound is projected directly onto a parameter that when changed, doesn't affect the sound so much.

S: Yeah, ok.

D: But you ... so you preferred the ones where it was more obvious of a change?

S: Yeah I preferred the ones where it was more obvious. Because it made you want to interact with it more.

D: Interact with it more. So it's not as explicit.

S: It's obvious, yeah.

D: How easy was it to use?

S: Yeah, easy. Like I said it was easier than I thought. It was very easy. I just thought that I would do it in a bigger room because ...

D: You'd rather have more space?

S: I was a bit worried about going in the table.

D: Mmhmm.

S: It was fine, but I just knew that I couldn't, like...

D: Once you realised that you could just go through the instruments rather than ...

S: Yeah.

D: Um, how does it compare to using a conventional instrument?

S: .... *pause*. It's very different.

D: Different how?

S: Because you don't ... I don't know. I think it's because you're not feeling the instrument. Like you're not... you're not. That's not the only reason but...because you're not ... if you're feeling it, a cube, I feel like you'd feel more like you were controlling it.

D: Ok, so the lack of ... um ...

S: Well, I don't know. I only know from guitar when you're like actually like, it's tacticle.

D: So it's not tactile. If it was more tactile, you'd feel like you'd be more inside the experience?

S: Yeah probably, but it wasn't worse than using...

D: Just different?

S: Yeah, just different. It's just something I haven't ... done.

D: How does the VR experience compare to a non-VR experience. *pause* So along the same kind of lines, you were talking about before.

S: So with an instrument you mean?

D: Well just in general. Do you think it being in VR changes the experience?

S: Oh. As opposed to doing it in another way, not like ... Yeah, I think it's cool. It makes it more ... I don't know it's something different. Makes it more... I guess you can tailor it to how you want it to be. I don... yeah... I don't really... I'd have to probably do an equivalent in non-VR to compare it.

D: Mmhm.

S: Or something similar. But I thought it was good. And I liked the buttons.

D: Is there anything you'd like to add to the experience overall?

S: No. It was very good. And I enjoyed... enjoyed using VR, because I've only really done videos. Well, I've done a game, but I liked how it was so interactive with the object. And.... it made you focus because you had to focus on like whether you were gonna accept or reject the sounds. Um. And it was fun.

D: Thank you very much.

F.2 VR02

F.2.1 Think-Aloud

S: Cor, it's good graphics isn't it.

D: It is, isn't it.

D: So you've got two controllers here.... can you see them?

S: Yep. I'll put my headphones in first.

D: So yeah, just explore. If you have any questions, just ask away.

S: Yeah, so. Here's an instrument.

D: Can you hear some sounds?

S: Yep.

D: If you can't physically reach it, you'll have to get a new instrument because...

S: How do I load an instrument?

D: So the buttons on the left.

S: Yep.

D: Push / Hold the trigger down, and push into it. Like, downwards.

S: Ok I'm holding it.

D: Ok, like, so on the left you can see the buttons. Turn left. On the side.

S: The save and reject buttons.

D: Yeah, so push into it physically. Like into the button.

S: Which one?

D: Which ever one you want, whether you want to save it, or reject it.

S: I didn't play that one.

D: Ok, so just reject it then. *pause* now you've got a new one. New sounds?

pause

S: So am I playing this now?

D: Sort of, but you need to pick the instrument. The cube is the instrument, so pick it up and move it around, so you can pull the trigger and... yeah. Ah there you go. So you can like throw it and stuff. Like twist it, and bounce it off walls. Do whatever really.

loud thud

D: *laughs*

silence

D: why don't you try like, if you throw it up in the air and let go of the trigger. And then try and catch it again, that might work.

S: Ok. So is that how... What I don't understand is how I'm supposed to interact with the instrument.

D: You just throw it around and move it in space. It's like ...

S: Ok, so you like...

D: It's not like... you don't pick it up, and it's not like ... yeah... just mess around with the cube basically. It should have an effect on the cube in some way.

silence

D: So when you save 4 instruments, it should start to load some. Like it will generate them.

S: So I've got another one. I've got a nice, chill rhythm going on. I'm gonna try and pick it up. And just do a circular rhythm, and see what happens.

D: *laughs*

S: So the sound's completely stopped now.

D: Stopped?

S: Yeah.

D: Well try moving it up or down, or like dropping it... or ...

S: Ok well, I heard a boing then. I'm gonna try some rapid movement.

pause.

S: Ok, so that sound is currently doing nothing. So I'm gonna reject that one. Ok so this is kind of spacey and synthy. *cough* it's quite intense. *laughs*. I'm gonna try and ... try ... ok.

D: So those numbers in front of you, on the wall.

S: Pardon?

D: The numbers on the wall in front of you. They're the genome of the instrument.

S: Ok.

D: In case you were wondering.

pause

D: What are you thinking so far? How are you finding the interactions and stuff?

S: Say again?

D: What are you thinking so far? How are you finding the interactions?

S: So, with this one for instance, when I moved up I could tell that it's changing the music. But with the other ones, I hadn't ... it wasn't as easy to tell.

D: Ok.

S: So I liked that. So when I threw it there, I could hear it changing.

D: What's changing about it?

S: The... it sounded like the progression reset.

D: Ok. So you prefer it when something more obvious happens?

S: Yeah... I think so because...

D: Sometimes when you're moving nothing seems to happen.

S: Yeah. Well I'm not sure if you're supposed to know how easy it is to make it change, if you see what I mean.

D: Uh huh.

S: Oooh ok. That is loud. Reject that. Rejection.

D: Yeah, so if you look at ... when you press the save or reject, if you look just above it it will tell you what is happening as well. So like literally above there, text will flash up saying ... something. So next time you press the button, try and look out for that.

S: Ok. So does it make a difference if I use one, or either one of these?

D: No. But you can like... so some of the parameters ... say for example some of the parameters might be ... like ... various positions in space, or rotation or velocity. Or like ...

S: Ah ok.

D: So it like it depends on... so you can throw it between your hands, and catch it, or throw it up and catch it, or like twist it around. Just try and play around and see what comes up.

S: So it's sort of a um...interludes of high-pitched noise at the moment. So...

D: How does it sound? Kind of annoying, or?

S: Ooh, so now the pitch has changed, and the tempo's increased a lot, I think. Ooh, and as I rotate it, that's changed the pitch, but kept the tempo the same.

D: Do you like that? Do you prefer it?

S: I like ... so this one's cool. It's in terms of... this one...

D: You like how it's modifying stuff.

S: Yeah.

D: So try saving it then I reckon. So if you want to save it, you can throw it at the button, if you want.

S: New instrument, mate. This one's kind of a low-pitch continous synth.

D: Ok *laughs*

S: That's how I'd describe it as. So, let's try and pick it up. So no change yet. I'm gonna try and rotate it ...

D: Anything? Nothing?

S: I can't tell actually.

D: Because it's too low or .. because ... ?

S: I'm gonna listen for a sec and see if I can recognise the whole progression and see if it changes ... I can't tell if I changed it. Ooh ok, yeah, ok.

D: Has something changed then?

S: That has introduced more tones. That sort of introduced some bass notes, I felt.

D: Ok.

S: So I'll put that this way. That doesn't seem to change anything. That does.

D: *laughs*. Why don't you try .. try throwing it up, in a straight line. So like let go of the... trigger.

S: Ooh ok.

D: Did something change while you threw it?

S: Oh yeah. It's gone.

D: It's gone

S: Ain't coming back. *laughs*. I like that though.

D: You liked it? So save it.

S: Yeah.

D: And see what it says when you press save.

S: Instruction number

D: Instrument loaded. So now, now the instruments are like, it's the next generation one. So fo the ones you've saved, it's some combination of the parameters that you loaded.

S: Ok. Ok, so this sounds more complicated.

D: Can you see how it says 101 at the front of the genome?

S: Yep.

D: Ok, so that bit of the parameter is the bit that it saved from the previous one. Because that was ... something about that parameter, that's what you liked about the instrument, so it saved that and moved it into the next generation.

S: OK. So this is sort of, it does sound like a combination of ...

D: It sounds like, of the ones you've saved, it sounds like some combo of that?

S: Yeah.

D: Ok, that's good.

S: It is quite quiet. I'm gonna try and move it over here.

S: Ok, that's increased the sound of the high-pitched notes I feel.

D: OK.

S: I'll try and throw it up. Ok. That's done a cool change now. I won't be able to catch it. Ahh!

D: Watch out there's a table in front of you.

S: *laughs*

D: Maybe just sack it off.

S: Ok, so I liked that one.

D: So now it'll give you the next one in the generation of instruments you've loaded.

S: It sounds like the start of Paris by ... *exhale* ... what's it called? *censored*. Ok I like this sound. Ok. The pitch has gone lower. And the tempo's increased, definitely. And then, the pitch has increased but the tempo stays the same. Ok. So yeah. So. Yeah. So it adds some high notes in when it's up here.

D: Mmhmm.

S: And it stays the same here. Ok. So that's... that seems to add high notes as well.

D: I'm gonna ask you to take it off in like a minute, so is there anything you'd like to say about the general thing while you're still wearing it? I'll ask you some questions afterwards, but is there anything you'd like to say, while you're in it?

S: I don't think so... I'll save this one though.

D: Ok. Are you happy to take it off?

S: Yeah.

D: Ok, thanks.

F.2.2 Semi-Structured Interview

D: So what did you think was happening?

S: I wasn't sure how to change the sounds at the start, but I suppose that's the experimentation stage. So once I knew what was happening, and you said there were a number of dimensions with which you could interact with, once that was clear, I could hear the difference between the actions.

D: So you'd rather ... did you enjoy figuring it out for yourself, or like, would you have rather had explicit instructions to begin with?

S: Personally for me, because of the complexity of the sounds, I found it hard to tell without instructions what motions would change it. But I suppose it's the combination of doing it in VR at the same time that does that.

D: OK, so were your first impressions? I guess you answered that a bit.

S: *pause* . I liked the sounds. That was my first impression, and then ...

D: Did you feel like there was a large space of possible sounds?

S: Yeah. Definitely. Definitely.

D: And so then, as your impressions, did they change as you spent more time inside the experience?

S: As I started to realise... yeah. As I started to realise the scope of what different sounds you could make. So at the start I wasn't sure if it would introduce different instruments or that. But then I realised that was, mostly synthesized music in different terms. So I once I realised that, then I felt it was easier to ... get the sounds I wanted.

D: How did you find the interaction with the instrument itself? So the ways... the scope of the ways that you could interact with it? How did you feel about that?

S: So I thought that... I liked the range of motions. I think it would be cool to have some kind of way of putting tempo in there.

D: Mmhmm.

S: So, sort of, percussive instruments. To me, that would be a sort of intuitive way to interact with all those objects, but I suppose it depends on...

D: So I guess, so you found some of the ones more intuitive than others? So when you said you raised it higher, it was getting higher, as opposed to...

S: Yeah... that was very intuitive.

D: How easy did you find it to use the instrument? Or the whole experience, how easy did you find it?

S: Once I'd experimented with it, then I could identify the ... the sort of axis of interaction, and then it was easy.

D: So for you it's very much so a... you want a ... when you pick up the instrument you're trying to figure out what the parameters that you're controlling. And then lock onto that, onto it. Rather than just interacting with it in general. In the space.

D: How does it compare to using a conventional instrument? *pause* Non-VR, piano, guitar - other rhymes.

S: Easier. To make music. Than most conventional instruments. It's preset in its scope. More rewarding in a sense because you can make it really quickly. And that's sort of the novelty of doing it in VR, as well.

D: Um... Yeah... how does the VR experience compare to a non-VR experience?

pause

S: It made me wanna move around a lot.

D: Inside the VR space? So did you wish you had a bit more space to move in? To like interact?

S: Yeah, I think it would be cool if you... if in my ... sort of ... you'd have sort of different locations, where sort of the preset instrument were.

D: Yeah

S: I know that's sort of like ... in terms of you...

D: Like zones?

S: Yeah, you'd have like a percussion bit, and maybe like a synthesis bit.

D: And then you could have different like bits to set them up, and then ...

S: Yeah. So almost like a DJ.

D: But you like the ... how did you feel about the ... kind of ... generative randomness of them? Because as you said there was a whole ... did you feel surprised each time you were using it, with what was happening?

S: I felt surprised with the different number of tones that I could hear.

D: Uh hm. Is there anything else you'd add other than what you said? Anything else you'd add to the experience?

S: Nnn... No. I think it'd be easier to give more answers if I had more ... a lot of more experience with synthesized music, if you see what I mean.

D: Mmhm. But in general, with the way you interact with things, and that. Excluding the music. Once you'd figured out what was actually going on with it, to interact with. It made sense?

S: Yeah, yeah. I'd say one thing which is letting the user know how many instruments they can use to create their next generation.

D: Ok. Yeah. It's 4 at the moment. So each time you save 4 instruments it loads a next generation.

S: Ah ok. Cool. Yeah

D: Cool. Thanks very much.

F.3 VR03

F.3.1 Think-Aloud

D: So have a quick look around first. You can't really move around much because of the space. The buttons are on the left and the cube is the instrument. And above, like the buttons is where text will pop up. And that's it.

S: Yep. Sound. And I use that right?

D: Yep, and you push the trigger down, and push against it, and it turns into a solid...

S: Yep. Oh Christ.

D: *laughs* Yeah that's gone.

S: Have I lost that?

D: Yeah I think that's gone. Yeah.

S: Nah easy mate *laughs*.

D: Nice.

S: Have you got the blue lines to set the area?

D: Yeah you can't walk out of those.

S: Sound.

D: Yep.

S: So hang on, if I like ...

D: Yep. Is that it? Yes, and if you do that a new sound should start.

S: "New instrument made". Oh that's quite nice. Hang on.

S: So what happens when you twist it?

D: So it's not, *coughs*, it's a random parameter each time. So it could be like velocity, or position, or....

S: Oh yeah.

D: Or rotation. And then it'll be a random sound that will change. So when you find something that you like, like save it.

S: It's really fun chucking it up ....

D: *laughs* yeah it is.

S: Did you procrastinate a lot just by doing this?

D: Yes. Come on, this is a formal experiment, don't make jokes.

S: Can you get juggling going?

D: You can bounce it off walls and stuff as well.

S: Ooh. Right. Right, that's quite a nice, er, violin sound.

D: Cool.

S: Oh god, hang on. Oh that is... That's like some techno stuff going on here.

D: *laughs*. Well, what do you think so far? How are you finding it?

S: Yeah, fun. It's quite, it's very engaging.

D: Engaging? Nice.

S: Um...

pause

S: I can't really tell what's changing for this one... I think I've lost it. Yep that's over the wall.

D: OK. *laughs*. The numbers in front of you are the ... uh... genome of the instrument. So that's like the specific parameters that are between it.

S: Ah so do they change when I move?

D: They change... they change each time you load a new instrument.

S: Oh!

D: So it's specific to the instrument, that's what's making the sound.

S: Oh, fair.

pause

D: How are you finding the general interaction?

S: Yeah yeah, very easy. Um. I'll save that one.

D: So when you've saved 4 instruments, it will start a new ... generation.

S: *laughs*. O-oh look at this. *laughs*

D: You can try throwing it against the wall as well.

S: To be fair... *bang* oh god! Ah I don't like that one.

pause

S: I quite like that. Did that one save?

D: Yeah, it should do.

S: Yeah.

D: So this is now the new generation. The next generation, so

S: Yeah.

D: So this is some combination of the previous instruments you were playing with.

S: Hmm. I can't really tell what's changing. Uhm.. Ooh!

D: Ah, it's gone.

S: ... the buttons are easy to press.

D: Ok, that's good.

S: I also like how you've got a nice little desk in here.

D: Yeah, it's nice. Anything else about the general ... how do you find interacting with the audio?

S: The audio?

D: Yeah, well the sound that's being made.

S: Yeah, yeah, that's, that's nice. I don't know where my block's gone.

D: So try pressing the button again.

pause

D: There's a new one there?

S: No.

D: Ok, I'll reload it.

...

D: Started again.

S: Sound. So if I ... the current music playing at the moment, that is just this one instrument, right?

D: Yep. There's only ever one instrument playing. But what happens is the bit that you're playing in each instrument changes ... each time. So like it could either be rotation or position, or like velocity, or it could be a vector of those.

S: Yep. So if I chuck this really fast, it should change the audio?

D: Something should change, hopefully. But in some way. But not necessarily in the way you expect. Is anything changing?

S: Yeah, yeah, I think the pitch went up. I've just lost it.

D: It's gone.

S: Yeah.

D: How do you find the space, you're interacting in?

S: I think it's alright. Maybe a bit close over here, but, as in, I think the rest is fine.

D: You've got enough space?

S: Yeah, I can reach easily back here, I can reach that easily.

D: Nice.

S: I like the toys as well.

D: Do you wish you had more visual feedback with what was going on?

S: Probably, as in, when you save an instrument maybe? Or it might be quite good to have some feedback on what's being controlled, or what's changing when you're moving it. So you know you've got this number on the wall ...

D: It doesn't mean anything to you because you can't...

S: So many if it was just like, what the parameter is changing. Even if the people... even if I didn't know what the parameter was, if I could see it when I chucked it up in the air, and the numbers were changing and what-not. Then that could probably... you could ... understand what's happening, you get more feedback on what's actually changing. At the moment .... *pause* that's quite a nice ...

D: So have you noticed at all that things have been carried on at all? So say you find a really nice parameter change, so when you pick it up, the pitch goes up.

S: Yeah.

D: If you save it, that ... one of the children instruments, or some of them will have that same ... uh ... way of interacting, but the sound that's being produced will be changed.

S: Yeah. I find they're very similar. Um, yeah, there's not one that's been completely different. As in, there's always some similarity.

D: Alright, are you happy to do some talking?

S: Sure. *pause* Ah, I was gonna put it on that table!

D: *laughs*

F.3.2 Semi-Structured Interview

D: So what did you think was happening?

S: Um, I knew instruments would be made over time with the save or reject button, and then this is just generated randomly, and then you can change parameters by chucking it around. Pretty much.

D: What were your first impressions?

S: First impressions? Uh.... I liked the room - I really liked the interactions. It's very engaging.

D: Did you feel ... how did you feel?

S: Very easy. Very natural. Because all the ... even the grabbing and stuff was done really well. As in, there wasn't any lag or anything there wasn't ...

D: And that's important?

S: Yeah. If it was lagging, or if the framerate was low, then that would cause some kind of sickness, and ruin the experience I think.

D: Mhmm. Did it change as you spent more time inside the VR experience? Your impressions.

S: Um ... I understood more what was going on. I don't know if my impressions changed.

D: Ok.

S: Because I was very impressed with it from the beginning.

D: *laughs*. What did you think with interacting with the instrument? Anything you would change about it? Or...

S: Uh ... mm... maybe the gravity? Sort out the gravity, the actual interaction itself was fine, but ...

D: So what, more gravity?

S: Uh, yeah.

D: So it doesn't fly away so much?

S: Yeah, so you don't lose the instrument, I suppose.

D: So you mentioned while you were using the instrument about more explicit feedback about how you were interacting.

S: Yeah.

D: With like what's changing.

S: Yeah. So maybe when you like chuck it up in the air, you have an idea of what parameters are changing.

D: So like numbers changing...

S: Yeah, numbers changing, or some sort of visual feedback, even if it's some sort of graph that's going up and down. That kind of thing.

D: So just something that shows you ....

S: Yeah, so you actually inherently know how it's changing.

D: Would you like to know more about how it works? Would you like some visual representation of what's going on underneath as well?

S: I liked the high-level, because I think if it was very low level , people may get very distracted and put off with what's going on. Whereas I think it'd take the engagement away from it, and well, not the fun necessarily, but people will be distracted away from the whole interaction.

D: So you said earlier, but how easy did you find it to use?

S: Yeah, very easy to use.

D: How does it compare to using a conventional instrument?

S: Um.... very different. I mean, I don't know, I don't play many instruments, so I don't know.

D: But in terms of ... how did you feel... how did it compare with a physical instrument? Did you feel like not having tactile feedback, or vibration made a difference?

S: Vibration might be a good idea. Like maybe if you're even just clicking the buttons, it might be a good idea to have some vibration, saying - you've saved it.

D: Would that make it better for you, the experience?

S: I think that would make it more engaging. Uh, but it wasn't a huge necessity. Just some little bits, I suppose to make it a bit more immersive.

D: How does the VR experience compare to a non-VR experience?

S: How do you mean?

D: Do you think that it being in VR helps the experience, or has not helped?

S: Um, well you wouldn't be able to just chuck cubes around, and change parameters round randomly if you weren't in VR.

D: Do you think that's a good thing or a bad thing?

S: I think that's a good thing. It's completely different, but I feel like it's a good thing.

D: And finally, is there anything else you'd add to the whole experience? You've mentioned some things, but is there anything else you can think of?

S: Hm... *pause* maybe instead of just having cubes, different shapes? Or even, an instrument?

D: Like a normal instrument?

S: Or even if the cube itself, was a different shape... I don't know, but as in, the cube changed when you were moving it? As in....

D: Something that adds another layer of visual feedback?

S: Yeah - so it could be changing shape when you're moving it. That may represent a greater velocity, say when it becomes bigger, or smaller vice versa.

D: Did you notice that the colours were changing? Did you think anything...

S: No, not really. I remember the last one being purple, and the first one was red or something, but ...

D: Ok. Cool. Thanks very much.

F.4 VR04

F.4.1 Think-Aloud

D: So yeah, try and say as much stuff as you can.

S: Uh, it's making funny noises. *laughs*

D: Could you pick up your left foot for a second please.

S: So to reject it, I just press here?

D: Yep, and you've got a new one?

S: Ooh. *pause* So I can't tell if moving it is changing anything - I don't think it is.

D: So the 3 main parameters that are being mapped are translation (position), rotation, and velocity. It can also be any kind of parameter, so it's not necessarily pitch, it could be like frequency or whatever.

S: Yeah.

D: They're gravity dependant as well, so you can try throwing it up and down.

S: Yeah. OK. *laughs*.

D: The numbers on the wall in front of you are the unique genome of the instrument.

S: So the gravity's quite low, which makes it a bit frustrating when you throw it up quite a long way. Ooh that's a bit quieter. *pause* So so far I can't really tell what's changing it when as move the thing, or throw it or whatever.

D: Each time it should be something different and random.

S: Right. Ooh I've lost tracking.

D: Sorry about that. Is that ok?

S: Yeah that's better.

D: Back?

S: Yep. Cool.

D: So yeah the mapping may not be like very obvious to begin with, but some of them should eventually ...

S: Ok. Yeah, it's not obvious at all, at the moment. Ooh that's a nicer one.

D: So when you save it, it takes some aspect of that and ...

S: Gotcha.

D: Adds it to the next generation.

S: It's gone quite... oh no it's ... so this one's stopped making sounds at the moment.

D: You could try putting it behind you as well - anything change?

S: Nothing. It's just all silent that one. Get rid of that guy.

D: So remember when you press a button, if you look at the text above it.

S: Ah ok, I'd forgotten, I hadn't seen that.

D: Maybe I should make it more obvious.

S: I think that it's a bit too high up and a bit too big. Because from my view I couldn't really see that when I was pressing the button.

pause

D: How are you finding the interactions in general?

S: Like, fine. Like any other VR experience, I guess. Um, I'm not able to tell what's changing anything - I can't figure that out. Maybe I'm not being patient enough, because I'm not leaving it in a certain rotation or whatever, but it's not obvious to me that anything's changing it.

D: Ok.

pause

D: So now of the ones you've saved, it's taken bits of those, it's a new generation.

S: Gotcha. Is it stereo or mono?

D: I think it's stereo, but the sounds aren't inherently ...

S: Gotcha, I'll keep both in then. Are the sounds supposed to be coming from the cube?

D: No. The audio is processed outside of unity, so it's not spatialised. Do you think it'd be better if it was?

S: I think it'd make more sense. I've also lost that cube ... now it's gone there.

D: You probably can try and get it.

S: Oooh.

D: So you think smaller text as well?

S: Yeah, I reckon so. Just because it's not really in your view. So if I'm looking here, and I'm like 'save', I can't see the text now, I have to look up and then I see it. And then I have to look both sides to look at it.

D: Yeah, yeah, ok.

S: Yeah, I do think audio coming from the cube would give you more of an idea that interacting with it is what changes the sound.

D: Ok.

S: Cus you'd hear it, if it was coming from the cube, you'd hear it move round with the ...from ear to ear like that. Because currently I have no idea that this cube has anything to do with the audio.

D: Ok.

pause

S: It's quite easy to accidentally throw it far too far *laughs*. It's gone too far away!

D: Yeah, you're not gonna get that.

S: Does it come back?

D: Nope, you have to get a new one.

S: How do I get a new one?

D: Hit a button, hit one of the buttons.

S: Ah ok, gotcha.

pause

S: I think something based on ... is there anything based on rotation?

D: I think ... 4/12ths of them should be ...

S: *laughs*

D: ... rotation based. But the parameter that it's controlling could be anything, so it could be like a filter, or it could be like ... something weird, rather than...

S: Yeah. Based on the rate of rotation, or the angle it's at.

D: It's the Euler angle.

S: Ok, yeah. So the rate wouldn't affect? So like spinning or that wouldn't have any effect, particularly?

D: No, not really, but the rotations are mod, so ... um ... they'd wrap around quicker.

S: Ok, gotcha. ... Instrument number 1 loaded. I've lost the instrument.

D: Ok, shall we finish there?

S: I don't know! I quite like this one.

D: Oh, ok.

S: So it's saying instrument number 1 loaded, what does that mean?

D: So you probably missed it, but it says 'next generation', every time it's gone back to one it means that it's a new generation that's been made. You know it's a new generation, each generation has about 6 instruments in.

S: Yep.

D: So it loads all of those, and then of the ones you've saved, it adds those to the next generation once the evolutionary process is complete.

S: Ok, because it said instrument number 1 loaded twice in a row then.

D: Did it?

S: Yeah. I think so ... which is what confused me, because I got that concept, but ...

D: So yeah, that says 'number 2'

S: Ooh this is horrible.

D: *laughs*

S: Sounds like, kind of bad bagpipes.

D: Ok *laughs*, I might pull you out of it.

S: That's cool, I liked it, some of the sounds are good.

F.4.2 Semi-Structured Interview

D: So what did you think was happening?

S: Um, well I already knew about your project, so I kind of thought my understanding of your project was happening, which was that, there's some instruments, and I listen to them and decide which are good and which isn't good. And bin the ones that aren't good. Get the ones that are good. And they carry onto the next generation. So that's what I know theoretically is happening.

D: Mmhm

S: Uh, as to what I think ... or what appeared to be happening, was pretty much that. You could kind of tell that some instruments were related to the previous instruments. I guess it was slightly hard to remember. You didn't know which, between generations of instrument, you couldn't remember 'oh

this is the one I liked from this generation' when it came around again in the next generation, I wasn't able to tell that.

D: Yep

S: Maybe if, I don't know if the cubes were coloured specifically, or was it random?

D: Random.

S: Because if the colours kind of carried through, that might be more helpful. So you'd know from the previous generation, the green one that you'd liked, was the next one that you got that was then green again. So that could be something that you could do. And it would work quite well I guess, that analog of colour would work quite well for ... um, if you had, so say if you had 2 in the previous generation. They got combined, you could actually, just do the colour between those 2 colours.

D: So do you think...

S: Whether that would actually be clear to people, I don't know.

D: So do you think in general having more visual feedback as to what's going on would be better, or worse?

S: Yeah, so, all the sounds are quite hard to distinguish, they're all quite similar I guess, the types of sounds you get. Certainly to me, they appeared to be like that. And that made it quite tricky to know that you were making progress, I guess.

D: Mhmm.

S: So visually, it's partially because I'm more visual than I am auditory ...

D: So say, as shown by the genome, each one has a unique set of bits that represent it. From that, if you had a bit more of a clear set of ... say if it was a different shape dependant on that genome, and then the next generation shapes were in the middle between those ...

S: Yeah, something like that, because, to be honest with you I didn't look at the genome number, because it was over there, and everything I was doing was either down here or down there. Um, so, and also it's a long string of numbers which I wouldn't have been able to remember which is which.

D: So you crossed this briefly, but how did your impressions change as you went along?

S: The sounds were getting better, I thought. You could tell that some that you'd said were good before, the ones you'd hated had gone, and the ones you'd said were good before did show up again, that similar kind of thing.

D: Ok.

S: So that was definitely true to a certain extent.

D: Ok. How did you find the interaction with the instrument?

S: Um, I couldn't tell anything changing as I interacted with it.

D: Ok, so you just thought you interacted with it, and each time you moved on, stuff was changing ...

S: Yes, because for me, the instrument sounded the same when it was sat on a table as to when I was holding it, and doing stuff with it.

D: Ok.

S: And there wasn't ... I don't think there was any point I could tell what I was doing was changing it.

D: Ok. How easy was it to use, in general?

S: Fine. Yeah, easy.

D: So you talked about it a bit, but how does it compare to using a conventional instrument?

S: As in, playing a conventional instrument?

D: Yeah.

S: Uh... very different. Yeah. I didn't feel like I was playing the instrument, because I couldn't tell any link between what I was doing, and the sound that was being made. But I did kind of feel like you were evolving it through the process of deciding which were good, for each instrument, when you had one instrument that you weren't, I didn't feel like I was playing that at all. I was there when it was playing.

D: So maybe you didn't feel like you were using a thing, more like you were inside something? Did you feel like your influence was maybe more secondary rather than ...

S: Yeah.

D: ... direct?

S: Yeah. I felt like I was the fitness function in your algorithm, rather than a player of the instruments.

D: So, how about the, I know you said you didn't really feel like you had much actual interaction, or having much effect, but how does it compare to a non-VR experience, versus like, the tangibility of an object, and how do you think that affected it?

S: I think I can see potential for the VR to be really useful, if there's more visual ... stuff. If the visual cues are used more. As it was, I'd say that actually having on a screen would have been, just as good,

probably, because you'd have had your genome number, you'd have had your instruction, and you'd have had your ....

D: Interaction?

S: Well because I didn't find the interaction to work, I wasn't really considering that I guess. But you'd have had those things, and you could have just decided yes or no, a bit more quickly perhaps, and had a bit more of an idea of what was going on.

D: Yep. So finally, is there anything else you'd add? You said some stuff, a lot about visual ...

S: So yeah, just visual cues as to what's happening, and I'd make it more direct. So you can really... I get that might be hard to do, I don't know, but ... yeah if there was something that felt like, you know as you moved it, you could tell. And I guess the obvious one is pitch, because you notice that, a lot.

D: So pitch is somewhere in the space of possible ...

S: Yeah...

D: But yeah, it's obviously quite unlikely that will happen very often.

S: And yeah I guess it's hard to notice if it's a filter changing somewhere in a thing, it's probably hard to notice that, because it changes over time anyway, and you can't tell if what you've done is because you've done it or just ...

D: So if you'd found a pitch interaction and had really liked that interaction, you could have saved that instrument. The interaction that is, say, moving up and down, and pitch. Uh, that bit would have saved, and that would have been carried on to a different set of sounds.

S: Yeah, I think that would have been good, I think that would have been fun to ...

D: So definitely more ... if you'd have had those, interactions where you'd be having more of a direct influence over what's happening would be good?

S: Yeah. Could one thing be, that you can indicate in, through some sort of visual ... what movement is gonna change something. Don't tell me what is gonna change, but, but have a .... a cube has an up and down arrow or something that tells you that as you move it up and down, something is changing.

D: Mmhm, as opposed to rather more exploring what's gonna happen, you're gonna ...

S: You'd still be exploring what was gonna happen, but you wouldn't have to search through all the different movements you could do. So, so you could tell them what would happen, you wouldn't have to tell them what would change, but you'd know that moving up and down was changing something because if you don't know that, you could move it around and you'd ... I didn't find out any of the things it was doing. But if I knew that moving up and down was changing something, I could move it up and down and you'd be able to listen really carefully as to what was changing.

D: Ok, thank you very much!

F.5 VR05

F.5.1 Think-Aloud

S: *laughs* I can't pick it up.

D: Ok, so ...

S: Ok there we go, ok. *laughs*. Yeah the gravity's quite low isn't it.

D: Yeah. Watch you don't walk into stuff as well, because it's ... it's ok, so probably just try and get a new one. So if you liked it, press save, if you didn't, press reject.

S: Ok.

D: You should have a new one now?

S: Yeah.

pause

D: What are you thinking Sarah?

S: Oh yeah, I need to speak. Um... the sounds are quite similar-ish.

D: Ok.

S: They're sort of, I don't know how to describe them ... harsh?

D: Non-musical?

S: I don't know if I like any of them. What happens if you don't like any of them and you reject them all?

D: Nothing, it just keeps giving you random ones till you ... but I might have to make you like some of them, in order to progress. So if try flicking it up, and then let go, and you might be able to grab it again if it comes within your range ...

S: Ah, it's gone over the wall.

D: *laughs* Sorry.

S: I did not like that one. Yeah, they're all really similar. I'm not sure what to say. I also don't know how to make it change.

D: So you can't notice any change?

S: Or... *pause* oh, oh, yeah I do, I do, I do.

D: Ooh.

S: A tiny bit though, it's not very obvious. Yeah.

D: Try maybe like walking around with the instrument.

S: Oh ok.

D: Oh yeah, you have to stay within that like, blue fence.

S: Woah! So loud.

D: Yeah some of them are really loud. If it's too loud just, uh, skip it.

S: I can't actually hear anything you're saying.

D: *louder* If it's too loud just move onto a new instrument.

S: What?

D: *even louder* If it's too loud just move onto a new one.

S: Oh ok.

D: How are you finding the interactions?

S: Yeah good. It's quite ... easy. Oh no I've lost that one.

D: *laughs*. That sentence has been said so many times.

S: Oh this one's much quieter.

D: Is that better?

S: Yeah. Definitely less overwhelming. Um... I don't know, I think I quite like the fact that the visual, that they're always the same, because it means you actually concentrate more on the sound, than what it looks like. You aren't sort of ... I don't know, I find that when I think of sounds, I think of them as like, 'round sounds', or like 'sharp sounds'. So like, not having the picture tell me that is sort of, I can make it out for, understand for myself.

D: Oh, that's good. I guess that depends on what kind of learner you are.

S: Different modes perhaps? Some sounds are definitely sharper than others.

D: Yeah. You probably can ...

S: Ooh.

D: *laughs* don't worry.

S: Classic VR.

D: How are you finding the controllers?

S: Um, yeah they're really easy to use.

D: Yeah, so when you press a button, look up, like above the ...

S: Oh yeah of course. Oh cool. So now I'm on the next generation?

D: No, it's still making new instruments. It'll say loaded when it's the next generation. It should say new generation stuff as well.

S: So if I ... the numbers, do they change?

D: The first 3 are which ...

S: *bang*

D: *laughs* don't worry. You won't be able to tell which is which, it's coded. But the first 3 are which parameters you're controlling, and which bit you're affecting with what movement.

S: Yeah.

D: The rest of them are the specific sound, so they'll get sent at the start to that, and then that changes. So say ... so how the generations work, is say you take, or like one bit of the sound, it'll take that interaction, and play it with the other sounds. So...

S:It is quite fun. It's quite immersive, I've never done like the VR thing like this, the other one I've done was like just watching.

D: Some people tend to find that you feel less sick. It's a little disorientating sometimes.

S: Yeah, it's nice. I quite like it.

D: I think everything being roughly the same size helps as well.

S: Well for me it's like, the height is fine. Perhaps the calibration is important?

D: Yeah maybe, we're roughly the same size.

S: Maybe you could do it per user, calibrate on each go?

D: Yeah.

S: Yeah I don't know, I find that I don't really like most of the sounds.

D: That's alright.

S: Um, cus they're sort of ... so you're trying to make a new instrument?

D: Well you're just trying to ...

S: From this?

D: You're basically exploring the possible spaces of instruments. If that makes sense. It's a smallish subset of sounds, and you're ... each time you're making a new one, you're exploring them, of those possible things, and deciding if you like interacting with them, and if you like the sound that's being made, or rejecting them.

S: Yeah.

D: So do you think you'd prefer the same kinds of sounds or a different set of sounds?

S: Yeah, something less electronic-y maybe? I don't know, because I ... I guess I'm thinking more of instruments. But with a violin for example, if you just play one of the strings, it's not necessarily gonna sound nice ... can I get that, is it too far?

D: Probably not, I'd probably leave it.

S: But it's when you're sort of, playing it in a certain way that it sounds nice.

D: Do you think you'd rather have a more direct influence over sound, or do you prefer the way it is now?

S: Yeah, so if you could change it in a much more obvious way, you'd feel like you were having a much more direct impact upon what was happening. And if you could sort of understand ... well with this one, this one's quite good actually because I can really, like, tell the difference between when it's just on the table, and I pick it up, it changes completely.

D: Yeah, ok.

S: So if that change in sound was really obvious, you could ... I don't know, control it better?

D: Yeah, ok. Anything else you'd like to say about the whole experience while you're still using it?

S: Um ... I don't know. It's a lot of fun?

D: *laughs* OK, thanks, I'll ask you some questions.

S: Feels a bit like I've just come out of the cinema.

F.5.2 Semi-Structured Interview

D: So what did you think was happening?

S: Um ... there was this little cube which was making these different noises and I was sort of playing with the cube to see if the noise would change, and then dependant on whether I liked it, I would like save it, or not.

D: What were your first impressions? And did they shift as you played with it more?

S: Uh ... I guess, I don't know. It was sort of ... *laughs*.

D: So what did you think by the end? What was your final impression?

S: So, that for me, it was like lots of the sounds sounded really similar. And maybe that's because I was just rejecting them all, um ... but it needed maybe more variation for then the results to be more ... noticable?

D: So in the way that it works, there's actually only one kind of very simple synthesizer that powers everything, so you think if you maybe had more different kinds of sounds, you'd ...

S: Yeah definitely.

D: And also you think, you said maybe more specific interactions, so you knew what you were gonna do, rather than, stumbling around more?

S: Yeah. Exactly. Because, I don't know if that's because I play an instrument, and so ... I know how things change, and you can sort of vary them by your, out of choice. Rather than it sort of coming up with it by itself.

D: Um... so how did you find the interaction? You already mentioned this briefly.

S: Yeah it was alright, I think I'm not used to using this thing, so a lot of the time I'm just chucking it far away ... but it was quite easy. Yeah, it was really easy.

D: How does it compare to using a conventional instrument, like a violin or a guitar?

S: Um, very different, because of the lack of control, I guess? I feel like it could actually become quite like ... you could make it like just as like controllable as a normal instrument.

D: Ok. So perhaps for you, do you think it would be better if it was more or less like a conventional instrument?

S: Yeah, I think so. Maybe a different kind of set of sounds. Or maybe like still you're controlling the sounds, and in, you have your thing and you're moving around, you hear the sound that you like, you like choose to keep it and then from that, I guess it'll develop something that is still controllable.

D: Yeah, that sounds good. So how did you find using the headset, as opposed to, not, maybe a screen or something physical?

S: I think it helped a lot. I think it was much more immersive, like that. I really liked that. I feel like I listened a lot more to the sounds as well.

D: So you said that at the start, do you think having the audio localised to the cube ....

S: Yeah that would be good. Having it come out of the box, so it's much more, sort of ... yeah easy to see how the change ... I don't know, realise that it is the box that is gonna ... and moving round the box.

D: So in general is there anything else you'd add to the whole experience?

S: So yeah, maybe just more sounds. But in general I thought the interface was good, I liked it.

D: What did you think of the buttons?

S: Yeah, I thought they were good. And then I guess the writing, I didn't even look at it, so maybe make it more visible. But other than that, I thought it was good.

D: Ok, cool, thanks very much.

F.6 VR06

F.6.1 Think-Aloud

S: So I'm in the room. I can't hear you very well so I'm gonna assume that everything is fine and continue. I can see numbers on the wall.

D: So the numbers ... can you hear me if I speak loudly?

S: Just about.

D: So the numbers are the genome of the instrument.

S: The DNA?

D: Yep.

S: Ah ok.

D: So if it goes out, just load up a new one.

S: Ah ok, so there's like a ... shelf of nice things.

D: The two buttons should be on your left, and you should have a new thing.

S: *laughs*

D: You can't walk there unfortunately. So what do you think so far, anything?

S: Uh, so far ... I'm intrigued by the numbers, I like that there's a shelf full of things, but I really want to use my projectile to hit them. That's my main aim currently. The sounds are nice ... well this one's not, but ... but right now, I'm interested in hitting. I've done enough experiments now to know I can't hit the animals. I'm now gonna focus on the boxes.

D: So, when you find one you like, it'll take one bit of the instrument, either the interaction or the actual sound itself and add bits of them to the new generations of instruments, once you've saved 4 instruments. And when you press the buttons, above them little pop-up text should appear after you press it, so try and look above it when you're done.

S: 'New instrument made'.

D: So now if you look on the table there should be a new one. How do you find the interaction?

S: Uh, this instrument's a bit screechy ... but I'm giving it some time. No I don't like it.

D: Ok.

S: Ah this is better, this is just a sort of, like, background fuzz.

D: That's nice.

S: I'm trying to work out if by just holding it in the air it makes a different sound. I'm gonna try throwing it. *pause* it's quite like nice and gentle, background noises.

D: Ok. It's probably gone.

S: That's ok, I like it though, I'm gonna save it.

D: Ok good.

S: Ah!

D: So when you've saved 4, it'll tell you about the new generation being made above the buttons.

S: Ah. So I like this one as well, so ... I'm gonna have a little play with it, but then I'm gonna save it. *pause*

S: OK, I'm gonna save this one. And this one's like bubbling.

D: Bubbling?

S: *imitates noise*. Again it's quite quiet, but I like that, it's like background music almost. Aah. I've thrown that really high. It's never coming back.

D: Ah ok.

S: So it still says new instrument made.

D: So I think maybe once you've done something with this one, it'll move on.

S: This one's sort of alright, but it's not as good as the others, but it's not as bad as some of the others.

D: It's up to you. There's a large space of possible instruments, so if you're not sure, maybe ...

S: Um, I'm gonna get rid of it.

D: So maybe you have to save one more ...

S: So I like this one, so let's save this one. Again, it's sort of discordant, but it's still quite jolly. Hey, generation 2 - genome mutated.

D: So now it's loaded. That instrument is now some combination of the past ones you were using..

S: Yeah you can tell, it's got the same sort of ... it's quiet, which are the ones I was choosing, and it's got the same sort of background 'plinky-plonkyness'.

D: Ok, that's good.

S: I was just looking around to see if anything else had changed around the room.

D: Unfortunately not.

S: But yeah, I like that. 'Instrument number 1 loaded'.

D: Zero-indexed, so ...

S: Yeah, again sort of quiet, a bit more discordant than the others. So I'm gonna, because I'm being a bit more picky now, I'm gonna reject that one.

D: Yep. Do you think you're having any direct influence over the sound?

S: Now that we're in generation 2, I do.

D: Ok. I don't mean in general through generations I mean specifically for an instrument, do you feel like you have much influence over what's happening? Or, is that important to you, or not?

S: Uh, it's not that important to me, but I want them to do a bit more when I throw them against the walls.

D: Ok.

S: Yeah, I think that would be nice. I think if that was having a bit more of a direct effect on the music. Because right now, it's like, it feels very much like it should go 'thonk', or ... should change the tone a bit more. But if it is, it's very subtle. But my enjoyment of it isn't being affected generally. And it's nice to have something to do while listening to music. And part of that is throwing nice cubes up and down, and watching them ...

D: And the interactions in general ...

S: Yeah, they're satisfying.

D: That's good.

S: The picking, and the pressing is slightly unintuitive. But the picking-up is good ...

D: As in the button?

S: Yeah the button. But the picking up is very nice.

D: What about the button pressing?

S: I sort of want to click as I press it.

D: So, if you're holding a cube, and you either like it or don't like it, you can hit it with the cube as well. Try that.

S: I like that.

D: So now you're on a new generation. Of the ones you've saved, it's the first set of those.

S: It's pushing me back a bit. Yeah, I very much like the picking-up. I feel very confident in catching it and throwing it around.

D: Yeah, after everything?

S: Yeah, like this is fun. I think the buttons could be a bit more like this.

D: A bit more cubic?

S: Yeah, I don't know. 'Instrument number 2 loaded'. And it's gone. But I like it. It was quiet and bubbly. Oh, this is great! This is my favourite instrument so far.

D: Really?

S: I'd quite like to be able to be like - definitely yes.

D: What about it do you like?

S: Uh, it's really fast. It's a little bit louder than the crazy quiet ones, and it's a bit like 'duh-duh-duh-duh'.

D: So do you think it's taken bits of the ones you liked and put them together?

S: Yeah I think so. I was picking quite fast ones, it's not too loud, I was getting rid of anything that was too loud, so it's not anything like that. And it doesn't have any of the really discordant things that I've thrown away.

D: Yep.

S: But otherwise, it's still quite different. I wouldn't have immediately, if I didn't have that information in my head, I wouldn't think totally that was a combination.

D: Ok.

S: So let's save it.

D: Is that it?

S: Oh, got a new one. So previously I would have said 'save', but it's not as good as that last one.

D: Ah ok. So you've got higher standards?

S: I've now got higher standards, I'm gonna reject it.

D: So you've now maybe saved ... there's not really an end at the moment, so you're just exploring, it doesn't produce one definite one that you like, but I guess you found something you do like. So for you, going back to that instrument you really enjoyed would be something you'd want to do?

S: Hm, yeah. I'm gonna save this one. 'Instrument loaded'. I definitely would have saved this one before because it's really quiet, and it's got the same bubbly texture, as before, but I don't know, are my standards too high now?

D: You've moved on.

S: Maybe I have, this is so last generation.

D: I'm gonna take you out after this instrument.

S: Ah, and it's gone.

D: I'm gonna ask you some questions, now. How did you find that?

S: Yeah, it was fun.

F.6.2 Semi-Structured Interview

D: So what did you think was happening?

S: I think ... you had already told me that the music was going to be a sort of combination of the sort of things that I had already picked. So I had that in my head going into it.

D: Is that a good thing or a bad thing? Would you have rather not known that?

S: I think I was glad I knew it, because it meant that I knew what I was trying to save, and what I wasn't. So when I went to click 'save' or 'reject', I had it very much in mind of like ... I felt very interested in seeing what the next geneartion would look like, based on my choices.

D: Ok.

S: I felt like the correlation between my choices and the output wasn't very strong. It felt a little bit like, sort of, maybe some of the extremities of the things I didn't like I had gotten rid of, weren't there anymore, but otherwise it still felt quite random.

D: Ok.

S: Uh, yeah. I definitely enjoyed myself. I didn't feel like the interaction I had with the cube was affecting the music very much.

D: Ok, so you were looking at more generation-to-generation rather than ... your interaction was somewhat narrowing the sound down rather than ...

S: Yeah.

D: But not massively? Rather more of a reducing of extremes?

S: Yeah.

D: So you mentioned this a bit, but what were your first impressions, and did they move along as you spent more time inside?

S: My first impression of the game was that I was very very interested in the mechanics of the controllers I was using. So, the picking up, the pressing of the buttons, the way I was physically interacting with the game, was the thing that was really holding my interest. It was only after a sort of few minutes of playing that I really started to focus on the sound.

D: Yep

S: Um, I was determined to knock those animals off the shelves, I tried sort of 3/4 times, I think 4 times is about the cut-off where you go, OK I'll do something else now.

D: Yep, ok. So how did you find the interaction with the instrument.

S: Yeah, I thought, I would have wanted a little more dynamic changes with the sound, from how I was interacting.

D: Mmhm. So more ... specific control?

S: Yeah, I tried for a little while moving my arm up and down, and left to right to see if that had any noticeable affect on the sound, when it sort of ... when it didn't immediately sort of change, I started more sort of extreme things, like bouncing it off the walls, seeing it cut through with the sound. So it was very much sort of waiting for something like that to start affecting it.

D: OK, so something that's come up before is - how important do you think visual feedback is to what's going on is?

S: I think it's quite important. I think, you would focus more on the sound if there wasn't anything to do, I think it would draw your attention much more inwards, like sitting with your eyes closed and listening to music, it's much more intimate experience.

D: Mhmm.

S: But at the same time, you might get tired of that very quickly. You might get bored, and the interaction was really nice, with the objects as well, it was a very engaging experience.

D: Yeah. So you might have noticed but the colours were changing of the cubes as you went along. Did that have any impact on what you thought, or ... ?

S: It made me slightly like or dislike the cubes a little bit.

D: Before you'd even interacted?

S: Yeah.

D: Ok. Personal colour preference spilling into instruments?

S: Yeah, I think one of them was a sort of sicky-brown-green colour, and I ...

D: Like the tobacco cases colour?

S: Yeah. Whereas the brighter ones I was, sort of, more excited to play with.

D: So some people have talked about certain sounds have more qualities, like pointy vs roundedness and some people have a preference for either kind. Do you think if that was fed into the instruments that would be something you would interested in, or?

S: Yeah, I would be. Yeah, if the shape you were handling mimicked the music somehow, that would be cool.

D: And also, so you said, through the audio, you could somewhat tell sounds being progressed down. If you had some kind of ... what would you do if you could affect the visual side into the generations as well? What sort of things would make sense to you?

S: It would be nice to see a visual representation of generations. So if the colours stayed more the same. Or if ... so there were numbers up at the top, in the DNA. I stopped looking at them very quickly, because I was sort of like 'oh, numbers'. Whereas if it were bar-charts, or some other sort of visual method of reinforcing the idea that these things are converging, I would have held my attention a lot more.

D: So another thing that has been interesting has been ... um ... you talked a bit about how you didn't feel like you were having a direct influence over the instruments, so for each instrument there's 12 possible things - modifications. Translations in x, y, z, the vectors of those. That doesn't necessarily make sense as normal interaction, but it's some sort of combination of those, and then rotation's the same 3 axis, and vector. And then there's velocity, so velocity x, y, z, and also the vector of that. So if I told you there was a specific indicator of ... would you rather there was a specific indicator of which one it was, or did you enjoy the fact that it wasn't.

S: I think I would have liked a specific indicator, I think I did enjoy the fact it wasn't, I did enjoy the sandbox nature of sort of just playing. But I would have experimented more if I had more information to work with.

D: And the same with the audio, there's ... it's broken down into, there's again about 12-ish things you can do, 4 of them modify parameters of an envelope controlling the sound, the shape of the sound, and 4 of them control it's a filter that focuses on a specfic bandwidth of the sound, and then there's also the other more meta values like the scale that it's choosing the sequence of notes, and then the speed of that scale, and also, um ... I think that's it. So then what happens is those bits are randomised, and then at the start of the genome, those are the bits that select which bits you're modifying with the interaction. So you're only modifying one bit. Do you think if I'd made that more clear that would have been better?

S: Yeah possibly. Like I said before, there's something to be said for the 'sandbox', just see what happens. Um, but I would have been listening out for it more, if I knew that the pitch was the thing I was choosing, then I might be more forgiving of a screechy loud thing, if I liked the pitch.

D: So do you think you're thoughts would spill down more? Say you liked a specific interaction with the sound, and you thought 'I'm gonna follow this through'. Say you liked rotating or moving, if that makes sense.

S: Yeah.

D: Ok. How does it compare to using a conventional instrument, non-VR.

S: Very, very different. I think using an instrument has a degree of skill involved, where you haev to practice and learn. Whereas this is very much you come to it very quickly, and there's a very low barrier to entry. Um, there is equally hand-in-hand with an instrument a level of satisfaction that comes with playing it, and playing it well, and knowing that you are responsible for music. In this the distinction between me and the actions I was making (the music was making) was a bit more hidden. It was a bit more in fog.

D: Ok. How about its physicalness, or tangibility? Or lack thereof. How did you find that in comparison to...

S: Right now VR is still quite novel as an experience, so it's exciting in that regard. In the way that picking up an instrument possibly isn't. There's something very nice about holding a physical, tangible instrument in your hands, and actually playing it, and having the noise generated physically. Um, but again the novelty of having the digital instrument and something that you can't feel in your hands is still quite nice.

D: OK. So anything else about the VR vs non-VR? So maybe in comparison to a screen, or ... playing a game?

S: Yeah definitely VR added something. I think if that experience I'd just done was on a screen I would have lost interest in the picking up and playing with the object much, much faster.

D: So finally, is there anything else you'd add?

S: I think I've covered most of it when I was there. Maybe having a few things to knock down?

D: Maybe more of an interaction? How did you feel about the fact that it was secondary action. So a lot of what was happening ... your gestures yourself weren't directly affecting it, with an instrument it's the actions themselves that affect it, but here you have much more of a secondary role. How did you find that?

S: I felt quite removed from the music I was making. It felt a bit like I was ... if someone listened to the final generation of my cube, I wouldn't necessarily feel like I could take responsibility for it. I would feel like I was a bystander in the experience.

D: Ok. Thanks.