Building Personalised VR Systems for Musical Interaction

Case for Support

Overview and Motivation

Virtual Reality (VR) technology has many applications, from uses in education[23], to uses in psychology, such as phobia-treatment[4], or as therapy for anxiety disorders[22]. In addition to this, the consumer music technology industry has been growing exponentially in recent years[20], which is increasingly becoming more driven by technology-based advancements. UK based companies such as ROLI are looking to beat their competitors by using novel technology advancements to stay ahead. In parallel, personalisation plays a key role in ensuring that users stay engaged with technology[8]. A technology that adapts to a user's needs allows a user to fully interact, and maintains their attention[16].

Genetic and evolutionary algorithms give a way to navigate a problem space — described by John Holland[9] as an optimization method taking inspiration from biological processes and natural selection. In situations where a numerical based fitness function is unable to be used, such as in the musical domain, where personal taste is a factor, a subjective, user-centric fitness function can be used.

This project aims to apply GAs to a Virtual Reality experience, in order to create an entirely new personalised system, with the potential to drastically increase a user's level of immersion, and thus increasing the impact of the experience upon the user.

The work done by Tokui et al.[21] around Interactive Evolutionary Computation (IEC), using Genetic Algorithms (GAs) will be built upon, with a larger set of selection methods. They only explore 2 options each for both crossover and mutation, in the context of timbral patterns, whereas our work will be applied to the larger space of multi-synthesis, with many crossover and mutation methods. This also builds upon the work done by Biles et al.[2] in generating jazz solos. The literature surrounding IEC is sparse, and more in-depth research is needed around it as a means of personalisation.

There are currently no clear metrics for quantifying immersion in Virtual Reality, and throughout this project we aim to create clear guidelines for how to quantify immersion. This would be applicable to all VR experiences, as it is the aim of the experience architect to maximise the immersion, whether that be a training simulation, or a creative experience. As there is minimal work to draw from, we will note what users discuss around immersion from the qualitative user study, and use this to form a clear quantification for immersion in VR.

Further, no such system exists that combines the benefits of Virtual Reality, Interactive Evolutionary Computation, and musical interfaces, and we predict that the combination of all 3 will yield a completely novel interface to create music with, as well as a new kind of music. Novel musical interfaces have always dictated new forms of music, from the creation of the modern piano, to the synthesizers in the 1950s, to the rise of personal computation and Digital Audio Workstations (DAWs) in the 1990s — each has brought with it a new wave of music. The creation of novel interfaces also drives forward the creative industry, encouraging competition and growth into a niche sector.

The system will implement and explore many kinds of audio synthesis, in particular physical modelling synthesis, whereby the waveform of a sound is generated using a mathematical model to simulate a sound source, building upon the work done by Mäki-Patola, et al.[15] to create virtual objects that can be manipulated. To this end, the virtual objects themselves, and their spatial dimensions, inform the creation of the sounds. The vast space of interactions that VR offers in comparison to reality, combined with physical modelling synthesis, has the potential to create entirely novel sounds — and methods of creating sound — leading to a wealth of new music.

The aspect of personalisation of VR in our system will hold for many applications across fields — a training simulation for a surgeon that has been tailored specifically to them has the potential to have a greater impact upon them. A phobia treatment that adjusts specifically to the user's demographic may lead to longer lasting effects. In addition, the immersion metrics we plan to form will benefit all VR experiences. With a clear way to quantify immersion, makers of VR content to treat anxiety, for example,

can ensure that the user is benefiting as much as possible from the experience, by trying to maximise their immersion.

Project Objectives

- To create and refine a virtual, interactive, evolutionary musical system, where users have a novel sound space to explore and personalise to their subjective viewpoint, working with an industrial partner.
- Peform an in-depth Semi-Structured Qualitative Study around the novel, open-ended area, and use this to inform the design, and publish findings as a paper to inform future work into other areas.
- Create and form quantifiable immersion metrics that can be used to inform all VR experiences
- Modularise and open-source each section of the system, so it may be reused.
- Demonstrate and show applications of research to other domains.

Programme and Methodology

Work Package 1 (WP1): Development and Implementation of the Personalised VR System

Research Leader: Dr. Stuart Discotheque, PI, Computer Science and Music, University of Bristol.

Principal Research Objective:

> To develop and test the system, using from existing in-house expertise, industrial partners, and other musicians.

This consists of creating the musical core of the system, forming a front-end end, and testing various genetic algorithms for suitability. These will be realised as concurrent work packages, with frequent meetings to ensure development proceeds smoothly. The three parts will be woven together consistently, so that by the end of the 3 work packages, a coherent system is produced. The PI will oversee the 3 sub-packages.

Work Package 1a (WP1a): Creating and Testing Musical Core of Project

Research Leader: Dr. Karlheinz Stockhausen, PDRA, Applied Music Technology, University of Bristol. **Other:** Rosa Lento, PhD, Computer Science, University of Bristol.

Principal Research Objective:

> To prototype and test the musical core of the project, using multiple forms of synthesis.

Principal Deliverables:

1. A complex set of Pure Data, open-sourced patches, that combine various forms of synthesis, in particular physical modelling.
2. Tested independently from the VR experience.

The musical back-end of the project will be realised as a complex hierarchy of pure data patches, covering a vast sound space. Researchers will take inspiration from various existing forms of synthesis, including wavetable, FM, subtractive, additive, in particular physical-modelling, to form a versatile synthesis engine to power the experience. The Physical-modelling synthesis will further the work done by Mäki-Patola, et al.[15] in using spatial dimensions and physical, mathematical models to create sounds from Virtual Reality objects. Various aspects of these will be combined and implemented in Pure Data, so it can be independently tested. As Pure Data, an open-source project, is being used, assets will be drawn from the vast existing set of open-source patches that exist. Industry partners and musicians will be consulted and regularly asked for feedback, to ensure the project is suitable for its users. The PDRA was chosen for this role due to their experience in creating synthesis engines, and will lead the task. The PhD student will aid in the testing, exploration of surrounding material, and prototyping of the engine.

Work Package 1b (WP1b): Designing and Testing the Front-End User Interface

Research Leader: Dr. Giovanni Silencio, PDRA, Computer Science and Music, University of Bristol. **Other:** Tom Genetico, PhD, Human-Computer Interaction, University of Bristol.

Principal Research Objective:

> To develop and shape the front-end of the experience - an interactive environment that the user can freely interact with, in VR.

Principal Deliverables:

1. An interactive VR experience that users can walk around in, and explore.
2. VR guideline principles, taken from exploring existing work.

Creating and sculpting a VR environment requires constant feedback from users, and drawing from existing VR experiences, and current literature to inform design. Therefore, the PhD student will survey and outline the key features of existing popular VR experiences, particularly those incorporating music, to design a set of guideline principles that are used to create the VR experience. This will develop the work outlined by Steuer[18] in defining factors that increase immersion, and draw from the work done by Stoakley et al.[19], drawing from urban navigation design to sculpt user interfaces in VR. Other local VR companies, such as Bristol VR Lab, and Aardman, will be consulted, along with other music technology-centric industry partners, such as ROLI, to best inform and shape the design. The front-end will be developed using Unity, and other assets, such as VRTK. These stakeholders have agreed to collaborate with us through the process. In addition, the work done by Serafin et al.[17] around design principles for Virtual Reality Musical Instruments will be drawn upon. This work is assigned to the PDRA due to their existing expertise in the area, who will focus on the development of the guidelines and the project. The PhD student will help survey the surrounding literature and experiences, and will liaise with the external companies.

Work Package 1c (WP1c): Selecting and Testing of Genetic Algorithms as Back-end of Project

Research Leader: Dr. Stuart Discotheque. **Other:** Dr. Giovanni Silencio, Rosa Lento.

Principal Research Objective:

To explore, implement, and evaluate various user-centric genetic algorithms as a means of personalising VR experiences.

Principal Deliverables:

1. A paper describing the role of subjective, user-centric GAs in personalisation.
2. The genetic-personalisation side of the overall system.

Exploring subjective user-centric fitness functions will build upon the work done by Horowitz[10], Kim et al.[11], and Das[6], to abstract what yields good, exciting, and novel results. Various methods for expressing genotype, methods of selection, crossover and mutation will be experimented with and compared. This work will then be consolidated down into a paper, which will aid others in creating personalisable VR systems with genetic algorithms. Specifically, we will explore rank-based, stochastic tracing, fitness proportionate, and tournament selection methods. For the crossover, we will implement single-point, two-point, uniform, and three parent algorithms. Finally, for mutations, we will implement boundary, non-uniform, uniform, and Gaussian algorithms[7]. This builds upon the work done by Horowitz[10]. The work will be distributed between the PI and the PDRA, who will lead the implementation and evaluation of the genetic algorithms, and the PhD student, who will explore existing literature, and prepare work for the paper.

Work Package 2 (WP2): In-Depth Qualitative Study and Analysis

Research Leader: Dr. Karlheinz Stockhausen. **Other:** Dr. Giovanni Silencio, Dr. Stuart Discotheque, Rosa Lento, Tom Genetico.

Principal Research Objective:

To plan and perform a rigorous, exploratory, Semi-Structured Qualitative Study, the analysis and results of which will be used to inform the design of the system, as well as to produce general guidelines surrounding personalised VR experiences. In particular, we will note what users discuss around immersion levels in Virtual Reality, and explore which metrics can be used to quantify this.

Principal Deliverables:

1. General observations, guidelines, and recurrent themes analysed and discussed.
2. List of key improvement objectives to be fed back into the prototype.
3. Guideline immersion metrics for experiences in VR.

Due to the uniqueness and open-ended nature of the system, it is best suited to a Semi-Structured Qualitative Study, as described by Blandford[3]. Users from a large demographic, and range of musical

abilities, will be asked to interact with the system, describing their thoughts using the 'think-aloud' [14] methodology, and then Semi-Structured Interviews will be performed, around many key factors. Through this, the audio and video will be recorded, and then transcribed. This will then be subject to thematic analysis to draw out the key themes identified throughout the study. These themes will be consolidated into a paper that will be published. The work is split among the PDRAs, who will chair the studies, guiding it, and the PhD students, who will perform the studies, transcription, and assist with analysis. The PI will oversee the analysis.

Work Package 3 (WP3): Refinement and Adaptation of Technology to User Feedback, and Open-Sourcing

Research Leader: Dr. Karlheinz Stockhausen. **Other:** Dr. Stuart Discotheque, Rosa Lento, Tom Genetico.

Principal Research Objective:

Taking feedback from user study and incorporating into the prototype. In addition, the code will be open-sourced in agreement with the industrial partner.

Principal Deliverables:

1. Polished prototype, developed with industrial partner.
2. Open-sourced software, with modular sections so that parts may be adaptable for other's use.

With the user study complete, and a clear list of improvements to the prototype, these will be adopted and reincorporated into the design in tandem with the industrial partner, ROLI, to pull from their expertise. In addition, the code that comprises the project will be fully modularised, and made open-source, so that others may benefit from the work done. Throughout the project, a website will be kept and updated with details of the project, so that others who are trying to create similar systems may benefit further. The PI and the PDRA will lead the updates and liaise with the industrial partners, and the PhD students will work on the modularisation and open-sourcing of the code.

Work Package 4 (WP4): Immersion Metrics Refining, and Testing

Research Leader: Dr. Giovanni Silencio. **Other:** Dr. Stuart Discotheque, Rosa Lento, Tom Genetico.

Principal Research Objective:

From the user study, pulling out key metrics that quantify immersion levels in VR. These will then be formally written up, implemented and small scale tests will be conducted in which the immersion metrics is tested.

Principal Deliverables:

1. Immersion metrics guidelines for Virtual Reality.

As very little work surrounding quantifying immersion in VR exists, it is best explored as part of a qualitative study, whereby feedback from users will then be analysed, and abstracted upon in order to form metrics to quantify a user's immersion levels in the experience. We will work with existing developers of VR experiences to form this, such as Bristol VR Lab, Watershed, Aardman and Opposable VR. This will contribute to all forms of VR experience. The PDRA will lead the study, and liaise with the industrial partners, along with the PI who takes a background role, one PhD student. The other PhD student will run the tests for the immersion metrics.

Work Package 5 (WP5): Publicising of System and Metrics: Workshops, Festivals, Demonstrations

Research Leader: Dr. Stuart Discotheque, PI, Computer Science and Music, University of Bristol
Other: Dr. Giovanni Silencio, Dr. Karlheinz Stockhausen, Rosa Lento, Tom Genetico.

Principal Research Objective:

To demonstrate, publicise and encourage people to interact with, and use, the system. In addition, the metrics will be used and tested on other interactive experiences, and our system will be abstracted from, and used to inform other domains.

As the system will now be completed, various workshops will be held to demonstrate the project. We plan to hold educational workshops in schools, as well as attending various musical interface conferences, such as New Interfaces for Musical Expression (NIME). Further, the immersion metrics will be demonstrated and tested on existing VR experiences, and publicized, such as those by Bristol VR Lab. In addition to this, we will create a small festival, and collaborate with various UK based artists to demonstrate the product's use to both casual users and full-time musicians. ROLI will partner with us, and assist in organisation and demonstration. We devote a portion of the time to realising the applications of the work done to other domains discussed earlier. The work will be split between all the staff, with the PI taking lead. This is expanded further in the Impact plan.

National Importance

Personalisation in VR technology stands to revolutionize consumer VR technology, as well as having other applications, such as with sculpting individualized VR experiences for surgeons to train on, training pilots on cockpit controls, or educating nuclear reactor technicians in a non-localised environment. These normally high-stress, high-risk environments are unsuitable for training, as this can lead to mistakes where lives can be endangered or lost. Adding a personalisation element to these experiences makes each more hyper-specific to the user, and has the potential to increase their telepresence, and therefore flow better with the system.

Furthering this, the immersion metrics we hope to create stands to inform, and strongly impact, all VR experiences, such as those detailed above.

In addition, the UK has always been at the center of artistic innovation. The core music industry contributed £4.4bn to the UK economy in 2016[5]. Creating novel technology helps inform the creation of new music[18], and UK based companies, such as ROLI, are looking to be innovative, and thus look towards the technology of the future. New technologies open up the potential for novel, interesting forms of musical creation, which the UK, with its rich musical history, can exploit to create exciting new music. Putting the user back at the forefront of creative technology with user-centered design, steps away from distant point-and-click interaction, and encourages a more seamless experience for the user, minimising the technology gap — allowing users to enjoy, explore, and create more. By exploring this novel technology, and demonstrating to companies that there are possibilities for growth in this area, we will ensure that the UK stays innovative in its creative technologies industry. As the work will be done hand-in-hand with our industrial partner, ROLI, this will directly affect the UK economy. In addition, it is hoped the research done surrounding personalisation methods in VR will directly affect a wide range of other UK-based companies and services, looking to add novel VR technology, such as the NHS training surgeons[12], or in classrooms as a means to tailor education to an individual[1 13]. Our immersion metrics will feed directly into this.

Academic Impact

As very little existing research has been done around personalisation in VR (WP1c), the resulting software (WP3), and the qualitative study associated with the project (WP2) contribute to the academic community. The immersion metrics envisioned (WP4) will significantly contribute to the academic community, as it will provide a way for developers to gauge how immersed a user is, and they can therefore adapt their VR experiences so that it optimises this. It is also hoped that this impact will increase as further interest and resulting research are fostered around personalisation in VR, and the application of qualitative methods to Human-Computer Interaction (HCI) research. Exploratory qualitative studies in HCI are still novel, and mostly in the domain of social sciences. However, they can play a key role in situations where clear quantitative metrics aren't immediately obvious[3], and can pull out other information that would have otherwise passed under the radar.

Management Plan

As stated, the sub-packages within WP1 will all be carried out concurrently, with integrated feedback, and explicit modularisation of each section, with regular AGILE meetings to ensure that each package informs the other. This will also ensure that the different sections of the system may be incorporated together with relative ease when the separate packages are completed. For the next work packages, as the work mostly depends upon the previous work being completed, we expect them to run roughly

sequentially. However, in order to allow each work package enough time to be completed, we will have them overlap. In this overlapping time, preparatory work, such as surveying of literature, finding applicants for the study, meeting industry partners, and organizing and analysing data, will be done. We allow each package plenty of time in case any unexpected difficulties arise. This will involve liaising with the lead, and if necessary, the PI, to develop a way to move forward.

In general, each work package is managed by a person with previous expertise, that can best dictate how the work package can proceed, and to divide and delegate the workload evenly. This will allow the first work packages to run concurrently and smoothly. In order to maximise communication between staff, particularly in the first work package, regular integration mechanisms will occur, such as SCRUM meetings, quarterly meetings where all staff attend, pair-wise meetings, and workshops to solve any problems that may arise. Throughout the duration of the project, there will be three major workshops. The first will happen at the beginning of the project, to refine and shape the expected outcomes, and share domain knowledge. The second will happen before the user study (WP2), so that all staff know best how to conduct the studies. The final workshop will proceed before the final work package, to discuss the implications, outcomes of the system, and the immersion metrics. This will also detail how best to engage with the public and industrial partners to demonstrate our work completed. We also aim to explore other real-world applications of our project.

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Budget

Table 1: Spreadsheet detailing overall estimated expenditure.

Summary Heading	Heading	Cost	Total	Details
Staff	PDRA	£100,000.00	£300,000.00	*3 years*
	PDRA	£100,000.00	£300,000.00	*3 years*
	PhD Student	£100,000.00	£100,000.00	*3 years*
	PhD Student	£100,000.00	£100,000.00	*3 years*
	PI	£40,000.00	£120,000.00	*3 years @ 20%*
Equipment	VR Headsets + Controllers	£700.00		-
		£700.00		-
		£700.00	£2,100.00	*Vive VR Headsets*
	VR Ready PCs	£800.00		-
		£800.00		-
		£800.00	£2,400.00	*Dell Precision Tower*
Software	Nvivo	£330.00	£330.00	*3 Year License*
Travel	International NIME Access	£500.00		-
	Flight	£1,000.00		-
	Hotel	£500.00	£2,000.00	*PI*
		£2,000.00		*PDRA*
		£2,000.00		*PDRA*
		£2,000.00		*PhD*
		£2,000.00	£8,000.00	*PhD*
	National Travel	£800.00	£4,000.00	*x 5*
Experiments	Participant Recruitment	£10.00	£5,000.00	*x 500*
Impact	Workshops	£5,000.00	£10,000.00	-
	Music Festival Partnership	£5,000.00	£10,000.00	-
	Open-Sourcing	£1,000.00	£1,000.00	-
	Application to other contexts	£5,000.00	£5,000.00	
TOTAL			**£969,830.00**	

Justification for Resources

Staff

The PI will devote 20% of their time to the project, mostly surrounding supervision of researchers, direct management of work packages, industry liaison, and outreach. The PI is being funded for the full 3 years of the project, as they will oversee — from a managerial role — all the packages. They will also need to be involved in discussions throughout the project.

The two PDRAs comprise a significant proportion of the budget, as they each take leading roles in the work packages. Each PDRA brings a different set of skills from different background to the project. Their experience will be essential in bringing the project to fruition.

Two PhD students will also be funded, who will mostly take a background role throughout the process, as each will focus on their own work in addition. However, their unique skill sets will also be invaluable towards the success of the project.

Travel

As raising awareness of the work we are doing is essential throughout the project, in addition to staying up to date with surrounding research, we will attend the international NIME conference. The budget for the international conference is £2,000 per member of staff (£500 for conference entry, £1,000 for international flights, £500 for a week's accommodation and sustenance), netting at £10,000 for all staff. In addition, it is essential to liaise with industry partners, other academics, and other stakeholders throughout the process, and therefore we allocate £800 per member of staff for national travel costs.

Equipment

In terms of equipment, we require 3x HTC Vive VR headsets (£700 each) for development and demonstrating, allowing members of staff to work concurrently with each other. Staff will use laptops as allocated by the University. However, 3x VR-Ready PCs with Nvidia Graphics Cards (£800 each) are needed to successfully run the VR headsets without causing sickness. Finally, a licence for the Qualitative Analysis software Nvivo is needed, to code and analyse the data collected throughout the experiments.

Experiments

In the experiments, we aim to have 400 participants in the main study, and 100 participants in the post-study, surrounding the immersion metrics. Each participant will need to be remunerated for their time spent, at a rate of £10, totalling £5,000. The experimental space will be provided by the University.

Impact

As further discussed in the Impact plan, we expect to run workshops in 25 schools to promote the use of our system, and Virtual Reality technology, throughout the work packages. We allow £400 for each school, consisting of £100 travel for all staff, £100 for venue rental, £150 for catering, and £50 for guest speakers, £10,000 in total. In addition, we expect to create and partner with an existing music festival at the end of the project, in order to further promote our project. We have budgeted £10,000 in total for this, comprising: £4,000 for speakers, lighting, and general equipment rental, £5,000 for musician services to promote our project, and £1,000 for administration (ticketing etc.). Throughout the project, £1,000 is set aside to open-source the software, covering any potential over-time, or outside developers, that may be needed. Finally, £5,000 is set aside to demonstrate, and aid in implementing, the project to other contexts. For example, the phobia or anxiety treatments described above. This will be spent working with the NHS to demonstrate that personalisation in VR stands to benefit these treatments, and in addition can be used to increase the impact of surgery training. The cost can be broken down into: £1,000 for continued development, £2,000 for meetings, talks, and catering, and £3,000 for investigation into, and creation of, novel hardware that will enable the experiences.

Impact Plan

As discussed earlier briefly, our research will have a wide-reaching impact, due to the novelty of our personalisation methods in VR, the innovation of our creative musical system, and the unique immersion metrics that we aim to create.

At the start of the project, we plan to run a workshop where we engage with our collective work, and invite those interested along to provide their input into the system. This will consist of our key stakeholders, such as musicians, industry partners. This will be held at a technology-artistic hub, such as the Pervasive Media Studio, and will be open to the public. Here, we will foster interest around our project, and point them towards the various public engagement sessions we plan to run including: a festival, workshops, demonstrations and publications.

Throughout the work packages, we will work with our industrial partner, ROLI, to create a polished version of the system. We plan to use their industry expertise and connections to maximise the impact of our work, and our system. This will involve publicising the system at expositions, such as Music Tech Fest. ROLI have stated they will cover the costs involved with this.

We plan to make all our work open-source, so that others may benefit, re-interpret, and improve upon the work we do. In addition, we plan to have continual demonstrations of the system to various crowds, including musicians, DJs, and other music technology — and VR — companies. This will aid in demonstrating the benefit of our system to a wide range of stakeholders, and showing that novel technology can drive creative processes forward. This will be continued when we form our immersion metrics, so that VR content makers may make use of them in order to maximise the immersion of their experience. The immersion metric stands to have a very strong impact on the wider community,

We plan to collaborate with Bristol City Council to run a small music festival in Bristol, with various musicians attending and using the system, to vastly increase public engagement with VR technology, and foster interest around science, engineering and music — in particular showing that the boundary between arts and science, which has long remained firm, may be broken down, and may help each other to maximum effect. This has been allocated for in the budget, and time has been allotted from the work plan, as it forms an essential part of our work. We hope to have people of all ages and abilities attending and engaging with our work. We aim that this will demonstrate that our novel creative technology can indeed bring around new forms of expression and music.

Furthermore, we will pursue the normal academic channels, such as research publications, and conferences. We aim to publish in high-impact academic journals, such as ACM, and we will attend New Interfaces for Musical Expression (NIME) to convey our own work, and draw inspiration from other surrounding work.

In addition, we plan to run workshops in schools throughout the project, to encourage VR usage in the young demographic. This allows those who may not have otherwise come in contact with the technology to fully experience and appreciate it. In these workshops, we will demonstrate and allow interaction with the various stages of our system. We also hope this will feed back into our work, so that we ensure that it is understandable and usable by a large demographic. ROLI will partner with these workshops to help maximise impact. We hope that through regular workshops like ours, VR musical technology may become as common in schools as conventional instruments.

To ensure that our work isn't strictly limited to the musical domain, we have allocated some of our budget for transferring our work to the other contexts described above, such as with the NHS to demonstrate the use of personalised VR technology in training surgeons, or as phobia and anxiety treatment. To realise this, we have allocated a proportion of our budget, and given it time in our work plan. We aim to spend some time abstracting the elements that can be incorporated to these problems, and have regular meetings with other parties (NHS R&D) to demonstrate how they could adopt the technology. We also aim to realise some basic prototypes for these parties to use. We have also partnered with the Government Nuclear Program, who are interested in making their nuclear reactor training experiences more engaging and life-like for users. They have allocated funds for this, and we hope to share our work with them throughout the process, in particular towards the end of the project.

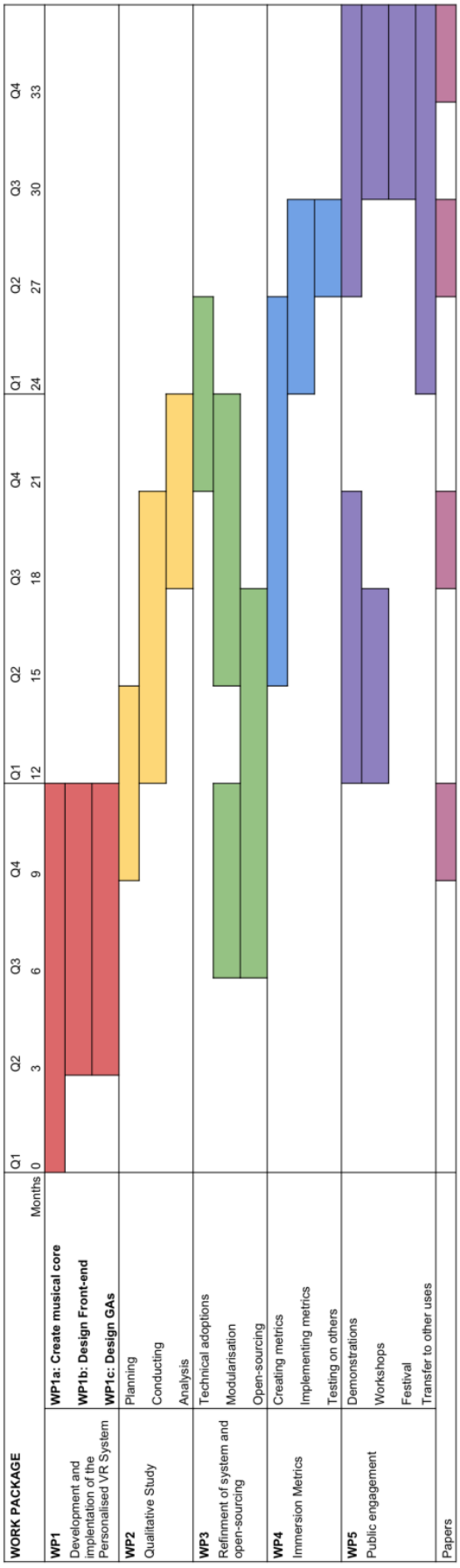

Figure 1: Workplan.