Respawning Originality Into Gamified Keyboard Practice: How Video Games Can Be Used To Practice Technical Skills For Adult Beginner Keyboardists

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I would like to dedicate this thesis to those who have supported my journey over the past four years. To my mother, Josephine: without your support and love, I would have never found myself rising to such accomplishments; although the last four years have been long and listening to my constant ramblings must have become tedious, you were always patient with me. To the rest of my family; James, Fred, Kate and Stephen: your belief in me as well as offering a place of safety which was free of judgement has given me the strength to never give up and ensure that my work reflects my own beliefs. To all of those I have had the honour of spending time with at ROLI, I thank you; the incredible mix of people and their interesting perspectives allowed both the research and me to flourish. Finally, to Chantelle: although you joined my life during the final year of the doctorate, your patience, kindness, support and love ensured I never gave up; you offered words of wisdom and insights I could never see and were the light that guided me through to the end. To all of whom that have been mentioned and to those that have not, I thank you for everything from the bottom of my heart.

Declaration

I hereby declare that except where specific reference is made to the work of others, the contents of this dissertation are original and have not been submitted in whole or in part for consideration for any other degree or qualification in this, or any other university. This dissertation is my own work and contains nothing which is the outcome of work done in collaboration with others, except as specified in the text and Acknowledgements. This dissertation contains fewer than 75,000 words including bibliography, footnotes, tables and equations and has fewer than 150 figures.

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Abstract

Learning to play a physical instrument (specifically, key-based instruments) and understand the intricacies of music theory can be seen as a daunting and large undertaking; this is especially true for adults who have never attempted to learn and want to learn independently in a casual capacity. A large majority of adult beginner keyboard learners will give up quickly after starting and never reach a level of skill in which they can express themselves freely with their instrument. Whilst there are many reasons for this quick drop off to the learning journey, a key reason that was established in context to this research was the lack of effect to the required amount of effort for learning. In addition, adult beginners lack crucial technical skills and knowledge to apply what they learn from lessons or to play what they may have perceived is possible; skills such as rhythm, audiation and reading notation. Learning these fundamental skills typically requires substantial amounts of rote learning and dedication which typically leads to boredom; the foundation that these skills provide ensures that learning is more fluid thus building positive associations with playing and leading to prolonged learning.

Whilst many solutions attempt to gamify the entire learning process or add gamification to existing learning solutions, there is a lack of research dedicated to learning based games which specifically help to practice these fundamental skills. This research outlines a novel approach to gamifying music learning in the form prototype training games, in which an original framework for designing and assessing said training games has been established; with particular concern to the transferability and meaningful application of the acquisition of fundamental keyboard and piano skills. The key intention of these games is to replicate a video game, and the high amounts of engagement that they elicit, whilst also being a method to passively acquire or improve new skills. This research pursues a distinct and original approach to this issue with the hope that using game-based learning in this context will increase practice, reduce frustration, build positive associations with learning to play a key-based instrument (and as an extension, other instruments or possibly other areas of education that require rote learning) thus reducing the swift drop off rates exhibited by a vast number of beginners.

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List of Abbreviations

VR - virtual reality
AR – augmented reality
GBL – game-based learning
EBI – equivalence-based learning
DAW – digital audio workstation
CD – compact disc
PC – personal computer
AI - artificial intelligence
MIDI - musical instrument digital interface
HCI – human-computer interaction
PSVR – PlayStation virtual reality

UI – user interface
IP – intellectual property
UX – user experience
SFX – sound effects
VFX – visual effects
BPM – beat per minute
RPG – role-playing game
FPS – first-person shooter
XP – experience points
DLC – downloadable content

List of Publications

Publications by the authors that contribute to this thesis include:

Components that helped contribute to Chapter 4 – Developing Games For Rote Learning and Chapter 2 – Literature Review feature in:

- Brett, J., Gladwell, T., Xu, N., Amelidis, P., Davis, T. and Gatzidis, C. (2020), Developing Games For The Purposes of Rote Learning for Keyboard and Piano, in '2020 IEEE Conference on Games (CoG)', IEEE, Osaka, Japan, pp. 724–727. URL: https://ieeexplore.ieee.org/document/9231779/

- Brett, J., Gatzidis, C., Davis, T., Amelidis, P., Xu, N. and Gladwell, T. (2021), Learning Through Play; a Study Investigating How Effective Video Games Can Be Regarding Keyboard Education at a Beginner Level, in 'The 16th International Conference on the Foundations of Digital Games (FDG) 2021', ACM, Montreal QC Canada, pp. 1–12. URL: https://dl.acm.org/doi/10.1145/3472538.3472555

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- Brett, J., Gatzidis, C., Davis, T. and Amelidis, P. (2022), The Crypt of Notation: Rote Learning through Video Games For Adult Beginner Keyboard Learners, in 'FDG '22: Proceedings of the 17th International Conference on the Foundations of Digital Games', ACM, Athens Greece, pp. 1–8. URL: https://dl.acm.org/doi/10.1145/3555858.3563276

Chapter 1

Introduction

1.1 Overview

This research is an exploration into how video games can be utilised most effectively within the context of music learning, with a focus on keyboard instruments. Current music related digital entertainment products and software either takes the form of video games which offer no educational attributes or are mostly outdated; the 'Guitar Hero' style of interactions still dominate the music education games market, but are solely focused on guitar practice and offer little to learning actual musical skills outside of their own applications. There is an overwhelming body of evidence that engaging with music learning offers a multitude of benefits to students and players of all ages. However these positive effects are only realised if students find playing enjoyable, rewarding and readily available. There is evidence that suggests music training has long term positive effects on verbal memory (Chan et al., 1998), can help reduce stress and maintain mental health (Jutras, 2006) as well as increase psychological and physiological quality of life in older adults (Seinfeld et al., 2013*a*). However, learning to play a physical instrument (in this case, key-based) and understand the intricacies of music theory can be seen as a daunting and large undertaking; this is especially true for adults who have never attempted to learn. There is a significant number of adults who want to learn to play the keyboard (key-based instruments) (*ABRSM*, 2018), but never reach a point of skill in which they can express themselves in the manner they desire. There are a multitude of reasons for adults to want to learn to play any instrument: it is an outlet for creativity, they are inspired by other competent musicians, they want to play with other likeminded musicians. However, one of the main goals beginners stress, founded through primary and secondary research (*ABRSM*, 2018), is the desire to play existing pieces; to be able to replicate the songs they listen to with their own skills which could later lead to

explorations of their own creative pursuits. These goals are substantial and as such require considerable amounts of dedication, both in time and effort of the learner.

The combination of a such an immensely high goal with the lack of understanding of the depth of learning to play an instrument, typically leads to adult learners dropping out of learning swiftly after beginning their journey (Evans, 2009). In fact, many statistics show that a large majority of adult beginner keyboard learners will give up quickly after starting and never truly reach a level of skill in which they can actually express themselves freely with their instrument – and this not only applies to keyboard, but any instrument (*ABRSM*, 2018; North et al., 2000). Researchers agree that there is "an alarmingly high proportion" of students who began to learn an instrument and subsequently abandoned this effort (North et al., 2000). Whilst there are many reasons for this quick drop off to the learning journey, a key factor that was established in context to this research was the lack of effect to the required amount of effort for learning. In addition, adult beginners lack crucial technical skills to apply what they learn from lessons or to play what they may have perceived is possible; skills such as rhythm, audiation and reading notation. Learning these fundamental skills typically requires substantial amounts of rote learning (i.e., repetitive actions) and dedication which typically leads to boredom; the foundation that these skills provide ensures that learning is more fluid thus building positive associations with playing and leading to prolonged learning.

A common and historical solution to help learners achieve their goals is an attempt to replace traditional lessons and tutoring using digital technology. This style of learning was originally based on CDs in which learners would follow along a series of guided lessons from their own home. Within the last 10 to 15 years, this style of learning has been adapted for mobile applications and implements gamified methods of playing musical pieces, as well as motivation through the use of gamification: adding leaderboards, badges and progressive user statistics. However, the issue with this style of learning is that it offers short term goals and ensures that the first few sessions of learning are satisfying and enjoyable which later leads to frustration when the content becomes more difficult and the goals require a lot more commitment without an engaging method of practice. Furthermore, their applications of gamification are also deemed as an afterthought and do not benefit the experience greatly. The idea of replacing the whole journey of individual learners with one solution is folly; learning styles vary greatly and the best methods for individual learners cannot be contained within one application.

Solutions found in research also share similar disadvantages in that a considerable amount of research is dedicated to only learning specific songs in novel ways; with the most recent trend to use either virtual or augmented reality. This once again offers a short-term goal with no real-world application as most learners, especially beginners, would not realistically

learn all songs like this; but, if they could read basic sheet music then they would be able to apply this to a much larger array of objectives. Whilst some research focuses on building gamified practice of specific skills, their application of gamification is rudimentary and lacks novelty – using leaderboards, badges and avatars. Finally, the validation of these solutions lacks real-world application, focusing on whether or not their solutions will do what they had intended, rather than focusing on how it can fit within a learning system. There is a lack of research dedicated to building video games which can impart musical theory knowledge and practical skills whilst also having a meaningful way to validate it.

Whilst many solutions attempt to gamify the entire learning process or add gamification to existing learning solutions, there is a lack of research dedicated to learning based games which specifically help to practice these fundamental skills. This research outlines a novel approach to gamifying music learning in the form of prototype training games, contributing an original framework for designing and assessing said training games; with particular concern to the transferability and meaningful application of the acquisition of fundamental keyboard and piano skills. The key intention of these games is to replicate a video game, and the high amounts of engagement that they elicit, whilst also being a method to passively acquire or improve specific skills. This research pursues a distinct and original approach to this issue with the hope that using game-based learning in this context will increase practice, reduce frustration, build positive associations with learning to play a key-based instrument (and as an extension, other instruments or possibly other areas of education that require rote learning) thus reducing the swift drop off rates exhibited by a vast number of beginners. As the late pioneer of video games Gerald A. Lawson once said, “To me, a game should be something like a skill you should develop — if you play this game, you walk away with something of value.” (Weber, 2011). The implications of this research are not only applicable to that of music learning, but also other domains of learning that are increasingly using gamification to enhance the pedagogical experience – languages, exercise and even meditation practices. The research intends to define a standard which does not simply ‘add-on’ game elements to existing learning solutions, but integrates them from the ground up.

A valuable open-source set of repositories is also provided which can help expediate the development process of creating music-focused learning games; including integrating MIDI, synthesisers, procedurally generated music and content and implementing rhythm which can be used alongside player mechanics and animations. Whilst this implementation considers the Unity Engine, the programming and design principles are applicable to any video game development style. Finally, whilst this set of repositories, and the framework of developing such games is most useful for independent developers or researchers, there is no restrictions on these principles and tools to be used by larger teams; it is important to note, however,

that the lessons and considerations were made specifically for independent developers and is most useful for this cohort.

1.2 Research Topics

There were three distinct areas of research that this doctorate was concerned with: keyboard learning (extended to general musicianship), video games and existing solutions to the key issue. Whilst not mentioned as a specific topic as it encompasses the entire research domain, the field of HCI is a considered overarching area as this research focuses on how users interact with digital artifacts using digital aided technologies.

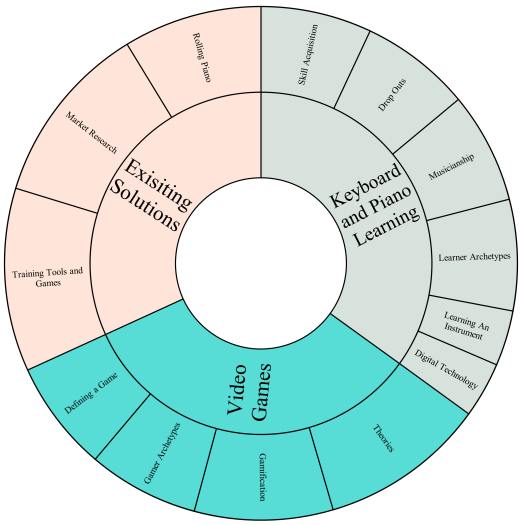


Fig. 1.1 Key Research Topics

The area of keyboard learning (or pedagogy/andragogy) was an essential arm of this research which helped to realise the main reasons adult learners struggle to maintain consistent practice and achieve their personal goals. The topic also helped to define the key learning styles and theories which are most closely related to the integration of game-based learning. The research topic of video games provided the backbone of the doctorate and helped to develop novel solutions in the form of a multitude of video learning-based games; the research explored theories of game design and gamification which helped highlight where existing solutions were falling short and how new solutions could remedy this problem. Existing solutions helped pave the way to a distinct and somewhat novel approach to solving the complex issue this research concerns itself with; guiding the researchers to the gap in knowledge of a lack of game-based learning regarding the practice of skills that typically require rote learning.

1.3 Research Questions

The specific topics in this research culminate in two specific questions. The original question which covers the much broader issue laid out in (section 1, overview) is summarised as:

- **How can video games help to reduce the high early dropout rates which are exhibited by adult, casual and independent beginner keyboardists?**

This question was explored during the beginning of the thesis in which the literature review, in conjunction with early primary research, highlighted the gap in knowledge regarding game-based learning and key-based instrument practice (specifically, practising fundamental skills which independent adult beginners would benefit most from). Whilst one can rather safely assume that a video-game experience would yield higher rates of engagement, especially as the target population for this research were adult beginners who had interests in video games, the research needed to explore how this could be the achieved through a series of developments and assessments in an attempt to answer the question:

- **Can adult, casual and independent beginner keyboardists passively acquire or improve specific skills, which typically requires rote learning and have meaningful real-world application, through playing video games?**

If the research could prove that a learning-based game could be a valid method of practice and the play sessions would be able to improve specific skills, which had real-world applications, then the future directions would be to validate this over long periods of time and with more serious applications (exploring other types of learners and installing such methods in more traditional styles of learning such as classrooms).

1.3.1 Significant Original Contributions to Knowledge

The contributions, in which originality and significance can certainly be argued, are summarised with three distinct points:

- Artifacts in the shape of novel prototype video games
- An original framework for designing and developing musical training games with repositories which others can use specifically for music games (but the principles do apply to other learning games)
- An original method of assessing gamified training tools which considers transferability and real-world applications

The artifacts that have been outputted are novel but were constantly reviewed with the intention of being valuable to the target population of this research. Whilst research within this field often develops solutions for the sake of novelty, using new technologies in a lot of cases, this research attempts to develop novel solutions without over designing ideas or using technology for the sake of using it. Thus, the final artifacts are both novel whilst also retaining meaningful applications to real-world situations, which are highly functional for both the learner and the developer or teacher. To the knowledge of the authors, there are very few, if any, attempts of using game-based learning within the context of acquiring skills that require rote learning in regard to musical keyboard education. Finally, when seeking advice or guidance on designing and developing such concepts, there was a lack of data. Thus, a key contribution is a framework for future researchers, or developers, to adhere to when developing such learning-based games whilst also offering insights into how to assess such concepts in a meaningful way. As mentioned, a repository with code that was used throughout the project is offered and can help expediate the development process for potential future researchers in this field.

1.4 Thesis Structure

This thesis is comprised of 8 chapters in total, which includes 4 experimental chapters. The remaining 4 chapters are the introduction, background research, preliminary research and a final discussion chapter. The background research covers 3 distinct subjects in which this research is founded upon: keyboard and piano pedagogy, video games and existing solutions. Through the review of literature, the gap in knowledge is explored, whilst the preliminary research that was conducted simultaneously helped to provide primary data to the support the findings of the literature. The preliminary research chapter outlines the development of the LUMI and consequent mini games that were used for practice alongside or within the application. An in-depth review of the games is outlined in which limitations of using VR and AR are discussed; finally, the key limitation of poor assessment methods and a lack of organisation is discussed. These limitations led to the first set of developed mini games which is outlined in the first experimental chapter.

Chapter 4 explores the suite of mini games that was created, which offers an in-depth report of the various prototypes made during this stage. The overall development process and pipeline is discussed, whilst mentioning key pitfalls to avoid and design principles to adhere to. This is followed by a discussion of the first study which was conducted to assess the mini games and to determine an ideal audience, narrowing in on how to assess the validity of these games regarding their engagement and educational impact. The initial study showed a

need for specificity in which Chapter 5 discusses the various games that were designed and developed for the specific purpose of improving a learners ability to read basic music notation. Chapter 5 also describes the second study which was conducted to assess the novelty of the solutions, pursuing a more quantitative and replicable approach to assessing both engagement and usability – using questionnaires which have previously been validated within this area of research. Chapter 6 then discusses the final prototype game which was developed and used within a longitudinal study. The chapter describes a pilot study that would be a much smaller scale instance of the final longitudinal study which would help validate the methods of engagement, usability and pedagogical value; improving upon the key limitations found for larger scale studies. The final experimental chapter provides significant details on the continuation of the development of the final prototype game, named 'The Crypt of Notation', before delving into the details of the longitudinal study that was conducted to help assess the game's learning potential in real-world contexts.

The final chapter helps to summarise the findings of the whole doctorate whilst also providing the major contributions that this research helped to create. The contributions are related to three key areas: design and development principles for future researchers as well as the key lessons learned and insights gained regarding the assessment of such novel concepts. The author hopes that future researchers or developers can learn from and expediate the process using the contributions – leading to the development of solutions which offer transferable skills and meaningful applications to learning to play key-based instruments (and potentially, apply this to other instruments or areas of learning).

1.5 The Placement Company

This thesis covers work undertaken within an engineering doctorate. The entirety of this research was undertaken at formerly, ROLI, now, Luminary (*ROLI*, 2022), based in London. The company was focused on keyboard manufacturing regarding the prosumer market before this research took place. During the course of the doctorate, the company shifted to manufacturing hardware which was tailored to the consumer market in the form of a fully light-up RGB keyboard named, LUMI Keys. LUMI Keys (*LUMI*, 2020) was built with a companion learning application and this research helped to improve the ecosystem of the software by developing video games that worked either alongside or within the learning application. The insights gained throughout this research have helped guide the development of such games within the learning application whilst also helped to make further considerations to enhance the experience of beginner keyboard learners using prototyping and extensive user research.

1.6 Accompanying Materials

The artifacts that have been discussed can be viewed through accompanying materials. This includes playable prototypes of many of the games discussed in the thesis as well as videos and screenshots of the games. Whilst not all games are mentioned in the thesis, most prototypes and concepts can be viewed at:

- GitHub Repositories
- Prototype Sample Footage

Chapter 2

Background Research

2.1 Chapter Introduction

This literature review covers 2 distinct subjects in which this research is founded upon: keyboard pedagogy and video games. Within keyboard pedagogy, the definition of a musician and the consequent skills that make learning to play key-based instruments are explored. The exploration of learning to play an instrument, and the target learner groups that this research is particularly concerned with is defined. This is followed by a review of relevant literature, as well as drawing upon primary research and personal reflection, to help understand why there is a fast dropout rate exhibited by significant numbers of keyboard beginners, particularly adults. In the context of this research, the main reason is described as a lack of skill and the lack of correlation between required effort inputted to learning and the lack of effect outputted. Various definitions are offered to help understand what a skill is in this context, how one acquires such a skill and the relevant learning theories that relate to acquiring or improving a skill. The final section of this review, video games, helps to define what a video game is, how gamification and game-based learning is used within a pedagogical view and how it has not been utilized correctly for the purposes of training specific skills related to playing an instrument. The section offers various theories of game design which have been considered throughout this research and helped to create a novel method of acquiring, or practicing, skills that are imperative to playing key-based instruments.

2.2 Keyboard Learning

This section is used to build the foundation of the main issue this research helps solve, and furthers current solutions in pursuit of reducing the high amount of early drop outs observed

with beginner keyboardists. Specifically, the definition of what it means to be a musician and by extension, the very skills that comprise learning to play keyboard or any particular key-based instrument is explored. This is then followed by relevant literature which discusses how one learns to play a key-based instrument and how digital technology has advanced in this field, specifically, digital solutions for independent learners. Specific learner types are explored, in which the research begins to narrow in on who suffers the most from early drop outs, and would benefit from gamified learning. Literature is explored into reasons for observed high drop-out rates and how the use of video games can help to solve this issue. As the main reason for the observed dropout rates is defined as a lack of skill, at least in the context of this research, the final area of literature concerns skill acquisition.

2.2.1 Musicianship

Musicianship can be interpreted in many ways: by definition the quality of music is subjective and opinions vary greatly from person to person, defining musical skill is therefore tricky and hard to objectify. However, from a scientific stance musicianship qualities can be broken down into specific criteria of assessment. Literature was consulted to help define what musicianship is and to provide a simple but effective description that could help give insight into the key areas of knowledge and skills that require the most rote learning, and where the design of novel game-based practice solutions could be most effective. Whilst there are many complex definitions which consider many aspects (how to define creativity within an individual [ref], possessing innate abilities to engage with music [ref]), utilizing the definition which West has defined (West, 2015) was deemed most appropriate. 'The Big Five' focuses on internalizing what is being heard and played, which is defined as the skill of audiation. West further defines instrumental abilities in five areas of musicianship (which are listed below). Using this definition allowed specific areas of musicianship which were considered fundamental, as well as requiring copious amounts of practice to be committed in their mastery, to be focused on. The five points in 'The Big Five' musical abilities are:

Rhythmic ability can be defined as one's skill at performing rhythms in the context of steady time. One's rhythmic ability is independent of one's notation ability. A student may have a well-developed internal sense of rhythm without the ability to read rhythmic notation, and vice versa

Tonal ability is the skill of differentiating pitch in the context of a tonality. As with rhythmic ability, a student's tonal ability is independent of the cognitive function of understanding notation. A student may have a well-developed sense of pitch without any cognitive ability to read tonal notation, and vice versa

Notational ability is the skill of reading and writing music on a musical stave. More experienced musicians could become sight readers or at least be able to hear music through reading notation and see common patterns. Many pop and folk artists sing and play beautifully without knowing how to read notation. However, it is important to note that these artists were already familiar with music from an early age. An inexperienced adult learner will find this difficult but learning to read and improve their sense of tonality are required to succeed – like learning any language

Creative ability has many definitions (Running, 2008). 'I find it helpful to think of musical creativity simply as the student's ability to generate musical ideas apart from that which is externally dictated. Even when students are proficient at reading notation, using their instruments, differentiating pitch across a range of tonalities, and internalizing complex rhythms in the context of steady time, they are missing a crucial component of musicianship if they have not developed some sense of independent musical thought. ' (West, 2015)

Executive ability refers to physical attributes using an instrument. Edwin Gordon makes a distinction between executive skills and audiation skills. Executive skills are the skills involved in physically manipulating the instrument (posture, hand position, range, facility, breath support, embouchure, tone production, etc.), commonly referred to as "technique." (Gordon, 2012)

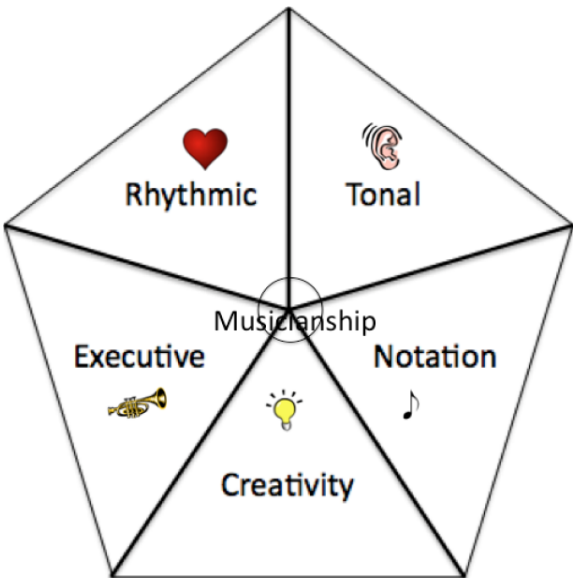


Fig. 2.1 The 'Big Five' Skills by (West, 2015)

While this framework of musicianship provides specific objectives of learning, it is important to note that becoming a competent musician is not solely based on mastering these elements but as West states, audiation is crucial; a musician can not only read the music but can feel and hear it. As West also notes, traditional practice and big band practice (the focus of West's research) teaches executive and notational skills and lacks the creative, rhythmic and tonal skills. The opposite could be said for casual learners that use applications and technology to learn, focusing on their creative outputs more so and using games to help strengthen rhythm whilst lacking the ability to play with correct form and to read musical notation.

2.2.2 Learning An Instrument

Learning to play an instrument can be seen as quite the endeavour and the study of playing an instrument is an activity which has evolved over the course of centuries. Whilst some instruments are considered 'easier' to learn than others, one must have at least some level of desire or passion to progress to any stage of playing an instrument. Traditional instruments such as piano, violin and guitar are typically associated with frustration when it comes to learning to play them, even at a low level (particularly in the context of trying to play existing musical pieces with the instrument – this is informed through primary research). The piano is one of the most popular instruments for beginners to pick up (Clark, 2021; Green, 2017) as there is an obvious relation to pitch and keys in an ascending fashion, as well being a great instrument for rich improvisation. However, reading musical notation for the piano is rather complex and is considered one of the hardest to understand. With any instrument, there needs to be a natural balance of challenge, frustration and boredom, as Levitin et al. (2002) suggests: "devices that are too simple tend not to provide rich experiences, and devices that are too complex alienate the user before their richness can be extracted from them". Playing key-based instruments does not quite match this balance as they can be considered too complex which leads to alienation and a sharp rate of drop outs.

The Learning Curve

Concerning the keyboard and piano in context to all over instruments, it is not a particularly 'efficient' instrument; whilst the ceiling for what one may consider mastery is almost non-existent, for an absolute beginner to achieve a status where they can express themselves freely with the keyboard or piano they must dedicate considerable amounts of time. Of course, this is in particular concern to what a learner seeks to achieve with their instrument and in the case of this research, the main outcome (in which market research has been conducted to

support this – see section 2.2.3) is to play existing musical pieces, rather than improvise or compose new ones. This dedication of time to 'master' an instrument can also be referred to as the 'learning curve'. The learning curve is used in most educational domains and is the "graphical representation of the progress in learning" (Jordà, 2004). The term is often used in marketing where solutions are advertised to 'ease the learning curve' and often misinterpret a 'steep learning curve' for meaning hard to learn, whereas this would imply a faster learning system (see figure 2.2 below for visual representation). Many authors describe the learning curve as the time it would take to either 'master' their instrument (Wanderley and Orio, 2002) or perhaps reach a stage in which they can express themselves freely (Clark, 2021; Green, 2017); typically, it is suggested that it requires 10 years to reach this 'mastering point' (Jordà, 2004).

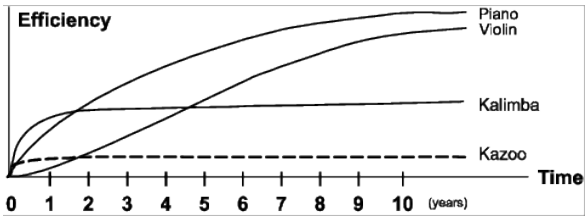


Fig. 2.2 Approximate learning curve for the (a) kazoo, (b) kalimba, (c) piano and (d) violin, within a period of 10 years

Whilst definitions of mastery and even suggesting critical stages on the learning curve for a given instrument is ambiguous, **?** did find a particular usefulness by comparing particular instruments' curves to determine which instruments are 'harder' to learn than others. Whilst the piano was a particularly tricky instrument, it's learning curve was steep (therefore, quicker) than other traditional instruments such as the violin. However, the learning curve is still not as shallow as other instruments such as the Kalimba and does require significant amounts of practice and dedication. This is a core reason for beginner casual learners of key-based instruments to give up shortly after starting: the effort inputted is not equal to the effectiveness of the actual practice and it begins to feel like an up-hill battle. Perhaps if there was a solution which could somewhat replace the recreational activities that learners would prefer to partake in, for example video games, and yet offer improvements or help to acquire new skills passively, this would ensure that their long journey up the learning curve is never truly abandoned and would inspire further learning over longer periods of time.

2.2.3 Learner Types

Demirtaş and Süral (2017) helped to define the individual learning styles regarding piano learning in an effort to make learning courses more effective for individual learners. Their study consisted of 133 music teachers and suggested that there are four learning styles:

Independent: independent learning styles relates to individual learners. Such students can categorize pieces of music they practice, analyse and interpret them from their own point of views. They prefer to learn on in a solitary fashion and exhibit high self-confidence. Independent learning styles can have some drawbacks in terms of students' vocational experience and performance (i.e., lack of tutoring can lead to poor form)

Analytical: Students who prefer analytical learning style adopt a conceptual view. Students try different methods and "...adopt solution-oriented approach in an effort to reach a solution." They prefer individual learning as well and such students like to work in safe learning environments and they like to divide their works into smaller parts by analysing challenges they encounter

Dependent: Students in a dependent learning group wait for an external warning. Guidance of someone else comforts students and makes students work better when they organize their studies. When they start to decipher a new notation, they first need to hear it from someone else and they always consult their works to be checked by someone. In the stage of working on a musical piece, they try to reach audio-visual resources and they play them by imitating rather than mastering n a musical piece, they try to reach audio-visual resources and they play them by imitating rather than mastering. A student using a dependent learning style has a more artistic and musical character as they access to various resources

Affective: A student adopting affective learning style looks for a familiar tune in a musical piece. Such students can better work if they like the pieces of music they play. They mostly prefer to play their pieces over and over in a wholly way. They always expect to take positive feedbacks during piano courses and if they take a negative feedback, they alienate themselves from the course; they can easily learn as they have high levels of motivation

Defining Specific Groups Using Market Research

Before developing any solution, it was important to determine who the target audience would be as the demographic for the research was still quite wide (adult casual keyboard

learners). Third-party user research conducted for the placement company (*ROLI*, 2022) as well reviewing literature, initiating casual conversations with learners of all skills levels to help determine an ideal audience for this method of learning and practice. Consumer research was undertaken by a third-party data company that specialises in defining user groups for specific use cases for the placement company (*ROLI*, 2022). Whilst the data cannot be made publicly available, a discussion of the summary of the data is outlined below.

Before developing any solution, it was important to determine who the target audience would be as the demographic for the research was still quite wide (adult casual keyboard and piano learners). User research conducted at the placement company as well reviewing literature, initiating casual conversations with learners of all skills levels to help determine an ideal audience for this method of learning and practice. Consumer research was undertaken by a third-party data company that specialises in defining user groups for specific use cases for the placement company (*ROLI*, 2022). Whilst the data cannot be made publicly available, a discussion of the summary of the data is outlined below.

The goal of the research was to understand consumer and hobbyist segments and how to best to engage with them when developing a roadmap. 23 consumer and hobbyists were featured in the market analysis, focusing on the UK and US across a number of locations. Overall, most casual consumers knowledge of electronic music and music creation is limited and most will have very little knowledge of music theory and the basic concepts of building a song from scratch. It was a common theme that most beginners seek to play music as an expressive outlet rather than a creative one, aspiring to play their favourite songs by other artists rather than becoming a full-time composer or producer of their own music. Finally, the research found that there was a lot of enthusiasm for educational tools and gamified musical learning but the consumers clearly felt that they needed to be taught authentic, tangible and transferrable musical knowledge and skills to remain engaged.

Two key user groups were defined: consumers and hobbyists. Consumers were made up of novices, instrumental learners and production dabblers whilst hobbyists consisted of lapsers, instrumental hobbyists and hobbyist producers. Below is a discussion of the two user types that were considered for this research: novices, and lapsers. Each type is described before discussing their key drivers, and attitudes towards learning. Whilst other user types had been, it was determined that these groups were not the right fit for both the ROLI target demographic nor for the solutions in the form of practice games – mostly because they were advanced learners and were not interested in learning an instrument.

Novices

Novices do not have a technical understanding of music, and see it as something to be casually consumed and enjoyed on a purely emotional level. They'd like to one day learn how to play music, which in most cases means learning a standard analogue instrument, and express themselves through playing songs by their favourite artists. Most have no concrete plan of how they'd get into music, and would need help to take that first step. They generally use music to raise their mood, and see it as something to help them through the most boring parts of their day. Taking up music is on their 'bucket list', and they want to learn first of all to boost their self-esteem and as an act of self-improvement. They see that playing music would be a means of expressing themselves, and to release stress. For this reason, they think they'll take up an instrument as a solitary hobby initially, and something that will give them the opportunity for quality me-time, although eventually they'd like to be able play songs they've learned with friends and family. Novices want their learning to be explicit with short bursts of work that are highly rewarding. Their learning should focus on popular music and would use applications that share similar structures to 'Duolingo' (Shortt et al., 2021) which offers a steady mechanic. They are the ideal group for practice games and were the main focus of this research.

Table 2.1 User Groups Defined By Third Party Market Research

	User Group	
Demographic Information	Novices	Lapsers
Current Focus	Getting Started	Getting Back Into Music
Musical Aspiration	Playing Favourite Songs	Returning To Old Skill Level
Technical Capability	None	Low
Instrumental Capability	None	Low
Musical Drive	Expressive	Expressive

Lapsers

This group gave up music after a disruptive life event, such as going to university or having a child, when the logistical challenge of continuing to play music was too much to overcome. Some have recently got back into music, and have gone back to their old instruments with the aim of getting back to their old level of skill using the same approaches as before. Others have the same long-term aim, although haven't had managed to actually get started. Lapsers see music primarily through the lens of their previous experience, and want to get back into music first of all as a way to relearn old skills and set themselves back on the path of

self-improvement. Whilst they have lower expectations of learning applications as they most likely did not use them before, this helps to entice them into using technology within their learning; they should be focused on learning reading sheet music and traditional paths of learning as this is what they are acclimatised to.

2.2.4 Drop Outs

The Associate Board of the Royal Schools of Music (ABRSM) surveys (*ABRSM*, 2018) offer some insightful data regarding the statistics of music learning within the UK. The most recent survey, conducted in 2020, consists of over 2000 teachers, 1500 children (15-17 years of age) and 1500 adult learners (18 and over). Differences between children and adults shows that more of children are involved in both creating and playing music compared to adults, although overall there is around a 20% decline in both groups playing an instrument with a fall of 11% in children participating in music lessons since 2014. Nearly two thirds of the children surveyed (64%) who had played an instrument reported that they used digital resources, such as YouTube and learning applications to support their learning; in 2020, two thirds of adults and children rated the value of digital technology in supporting their progression a 7 or higher on a scale of 1 to 10. Since the last survey of 2019, teachers from all music fields report that 90% of their learning content makes use of some form of digital technology. Of those who reported taking musical exams, only 30% of adults completed grade 1 and then tapered off, highlighting the need for consistent motivation and practice beyond the beginning stages. This is supported by 61% of teachers claiming that motivation, practice, commitment and enthusiasm are key factors for learners to make progress.

Drop Out Predictors

ABRSM surveys claim that the reasons behind why adults stop learning include a loss of interest, financial issues or they found lessons were not necessary; they wanted to just have fun. Interestingly, those that have taken exams or lessons and are successful feel a desire to carry on; the higher grade or skill level they reach, the more they play (i.e. encouragement comes from consistent acknowledgement of improvement (Gerelus et al., 2020; Ruth and Müllensiefen, 2021). Ruth and Müllensiefen (2021) observed that an increase in age from teenager to young adult was a strong predictor of dropping out; this is when younger learners tend to focus on other activities which suit their passions more or those that are academically inclined will focus on education more so. A retrospective survey of over 3,000 adults from the Swedish Twin Registry (Theorell et al., 2015) identified a multitude of reasons for drop out or continuation of learning which include: starting age of learning, teaching content and style,

and the environment that music teaching was administered - those that could socialise and interact with other similar learners was a key reason for continuing their learning (Chi-hung and Hartwig, 2011).

Whilst there is a large amount of literature regarding dropout rates for children learners, the issue is even more apparent with adult learners. Primary research conducted at the placement company of adult learners with various levels of experience showed that there is a desire for adults to play an instrument but the current methods of teaching and financial pressures unfortunately mean that a large majority of these potential learners will never attempt to learn. Even when an adult begins their learning journey, traditional keyboard teaching techniques, when combined with the wide range of individuals learning styles and motivations, results in a high dropout rate for learners. There are four main reasons for this (Cremaschi, Leger, Smith and Ilinykh, 2015):

- Institutional education techniques have not adapted to student motivations
- Students do not enjoy the process
- Cognitive load / Time load prevents desired progress
- Restrictions in the form of finance

Lack of Skill and Correlation Between Effort and Effect

Playing keyboard requires immense amounts of patience and effort. One of the most common complaints teachers receive from their students is that there is a lack of effect to their learning and the reality of learning to play simply takes too long and leads to disinterest. This is partly due to unrealistic expectations and this issue is not helped by learning applications and new methods of teaching stating they can help to expediate this process. This is further exacerbated when adults who want to learn independently in a casual manner. For these types of learners, their learning journey can take the longest and is most frustrating as they have no support or tutor to help point them in the right direction; often leading to frustration when trying to read a piece of music without any idea on the relationship between specific notation and physical keys. This highlights the need for a foundation of a strong skill set to help facilitate these learner types throughout their learning, particularly important during the early stages.

To further highlight this reason for drop offs, research into predictors of early drop outs showed that a key reason was related to musical ability (Mawbey, 1973); this helps further the idea that the more competent a learner is, the more likely they are to continue learning. The issue lies in the fact that adult beginners can never reach a level of satisfactory competency

with the current learning methods and thus never reach a level of competence where they are inspired to progress further. **?** studied predictors of early drop outs in which 55 former piano students were compared with 153 current piano students; the former students had quit learning to play piano within the previous year and had at least a year of experience before this. The procedure was to ask both groups of students a series of multiple choice, open-ended and Likert style questions to determine why they had continued to learn or why they had decided to quit. Through the research, they had found that musical achievements and comparisons to other students were a key reason for drop outs; those that were former students stated that they could not play to the same ability as the other students and would have less opportunities because of this. The other key reason found was that of environment. Results showed that motivation within home environments was lower when compared to classroom or tutor-based ones, further highlighting the need for extensive and new methods for engaging and meaningful practice outside of classroom-based settings.

Similar research was conducted by Costa-Giorni (2022) in which they were attempting to find differences in the general level of skill regarding piano playing and likeliness of drop outs also offers insight into this issue. They asked students who were currently learning to play piano and those that had dropped out (typically only learning for around a year) to complete a series of tests to measure musical aptitude. The results showed that there was only a slight difference between the skills of the two groups and also found a significant difference between how often each group practiced each week. Whilst there were not many significant differences between the two groups, besides from that of specific skill capabilities, what was a key indicator was a lack of motivation to practice on a regular basis and diminished achievement. When taking this into consideration regarding those that have had very little exposure to playing or leaning an instrument, particularly adult beginners, perhaps games can help increase this motivation and be used in ways that can offer support and a sense of consistent achievement.

2.2.5 Skill Acquisition

As one of the key reasons defined for this high amount of observed drop outs was lack of skill, and the consequent solutions seek to be a form of practicing specific skills, it is important to offer literature which helps define what a skill actually is and how one acquires it in context of this research. There are many definitions of skill, such as: “Understood as a special form of capability, with the connotation of a rather specific capability useful in a specialized situation or related to the use of a specialized asset”, (*ProQuest*, 1996; Salmela and Pärnistö, 2009), “... skill refers to any ability acquired by training or practice, allowing individuals to perform well in multifarious types of tasks. In this context, a skill is an ability that is acquired

through practice and by using declarative knowledge." (Pérez-Paredes and Sánchez-Tornel, 2009). It appears that the idea of skill and competency are synonymous, particularly in the field of psychology. The concept of skill is defined depending on the domain one discusses it, however for this research, the definition is related to how competent one is in carrying out a certain action and that it can be practiced or trained over time (whereas, in comparison to an ability, it is rarely something which is innately required). (Attwell, 1990).

If skill is a measure of how competent one is regarding a specific task, then it is highly measurable and new skills can be acquired or improved upon through practice; whereas knowledge is something which is learned once and revised and an ability is something which is more innate. Therefore, this research is concerned with methods of skill acquisition, particularly pertaining to skills which require copious amounts of repetition. Of course, this applies to musical skills, specifically that apply to key-based instruments, but these theories of learning are also applicable to any other domain of learning a skill that requires a lot of practice and consistent repetition.

Rote Learning

Rote learning can be defined as the memorisation of specific skill or knowledge through repetition. It is often used in classrooms to memorise certain techniques (within the domain of sport or physical education) as well as in theory (memorising times table or the periodic table with mnemonic devices). Whilst modern day teaching styles shy away from the use of rote learning, as it is more about association rather than understanding, it still has a place within learning. A chemist needs the information regarding certain elements which are found on the periodic table but what they do with that information cannot be acquired through rote learning (i.e., the application of the skill or knowledge retained). Other theories of learning attempt to either replace the method of rote learning or improve upon it, such as associative learning methods which include equivalence based learning or spaced repetition (see below). Ahmed and Ahmad (2017) asked undergraduate and postgraduate students to rate their use of rote learning during their studies in comparison to more in-depth methods of learning. He found that whilst most students would not opt to use rote learning, or surface level learning, they did indeed use it in some capacity, whether they were aware of it or not. He concludes with the fact that rote learning does play an integral role in learning and is not entirely about meaningless repetition, "…, rote learning helps students to become lifelong learners by motivating them through assessments on which they can score well in early years of higher education" (Donnison and Penn-Edwards, 2012).

There are particular learning theories which are related to rote-first methods, one of the most popular theories is put forward by Suzuki (*About the Suzuki Method*, n.d.). Particularly

applicable to this research is the idea of consistent encouragement and constant repetition. Similar to learning the phonics of letters and then words through repetition, music learning also requires a similar philosophy – listening to pieces repeatedly and reading scores on a regular basis. This approach is applied to areas of learning keyboard which require rote learning, these are typically areas of skills that are easier to build with children as they are less distracted and have more time to revise. These areas of skills, mentioned in the definition of musicianship are the foundation to quality form and method when playing and learning keyboard.

Kinaesthetic Learning

Three of the most popular learning styles are visual, auditory and kinaesthetic (a hands-on and more physical approach). Whilst all learners fall into a specific style, most will not be strictly one style or another and are a blend of all three. Specifically, this research has a focus on kinaesthetic learning as most of the learning uses some form of physical device. However, it is important to note that many of the solutions which were developed also consider the other learning styles. For example, all training games were developed to be played with some form of physical hardware, for the most part it was the keyboard, however there are other elements which help support the learning of these skills: audio as well as rich visuals in which a learner can begin to build associations with the physical. Throughout the history of research regarding learning styles (Price et al., 1981), most students use a mixed approach as outlined above but recent studies (Riazi and Riasati, 2007) found students prefer to be actively engaged in class activities and opt for a hands-on approach, helping to support the use of kinaesthetic learning in regard to this research; whilst outside of the scope of this research, embodied learning (Nadyrova, 2016) is becoming increasing popular.

Equivalence Based Instruction

Equivalence Based Instruction (EBI) is a technique established by Sidman (Sidman, 1971, 2009) where a student is taught to correlate set A to set B, and Set B to Set C then, equivalence is established in the learner where set A equals Set C. In some ways, this associative learning method is synonymous or an extension of rote learning which is useful for repetition but is more useful for building stronger connections for memorisation. The technique is directly analogous to the Light up key method of learning to play keyboard and useful for game-based learning, where Stimulus A = the Sound, Stimulus B = The Light (and later game elements), Stimulus C = Finger position / muscle memory. EBI has been successfully used to teach a wide variety of skills including: reading, picture schedules, geography, money skills and

sorting to both typically developing children and children with Autism. EBI procedures conducted by Zinn et al. (2015) found that EBI was significantly more effective in teaching basic course related vocabulary (i.e. drug names) than random sequence presentation formats, such as flashcards. Participants learned twice as quickly and with fewer errors than the control group.

Spaced Repetition

There are a number of emergent education techniques that aim to reduce cognitive load, and retention of acquired knowledge. One such technique is based on spaced repetition (Ausubel and Youssef, 2010), which is a phenomena where people will recall knowledge more accurately if they practice in short bursts over time, rather than massed practice (i.e., 'cramming'); spaced repetition is typically used in language learning but could be used within music learning also. The first model of spaced repetition was designed by Pimsleur (1967), who referred to the method as graduated-interval recall. An issue that Settles and Meeder (2016) found was that the approach was pre-recorded (like many learning programmes) and could not adapt to a learners ability, forcing to practice words which were either too difficult or easy. The emerging technique that Settles and Meeder (2016) laid out was referred to as Half-Life Regression, which takes into account personalisation of learning as well as difficulty of the content itself. Building on Ebbinghaus' model of memory (Ebbinghaus, 1913), also known as the forgetting curve, which states that memory decays exponentially over time, the new approach builds upon this formula, using machine learning and two feature sets: interaction features (i.e., how the learner interacts with the content) and specific tag features which help determine the inherent difficulty of each word memorised. Their study reported that there was an increase in retention of remembered words and engagement with practice after they had implemented their half-life regression model. This model of learning is adopted and the difficulty of specific practice techniques is considered to build a progression of practice for specific areas of skill.

It is important to note that this technique was pertaining mostly to recalling single words, typically from reading or hearing them, but this is not the entire process of learning a language – which is far more complex than recalling words or simple phrases. However, the combination of this learning technique in conjunction with other methods of education, such as tutoring, learning from friends and families or any journey a learner takes, is far superior to a method that attempts to teach the whole learning process (as the majority of current music learning applications attempt to).

2.3 Video Games and Gamification

As this research is focused on gamifying key-based instrument learning, it was imperative to conduct a review into gamification, game-based learning and game design theory to help pave a way to a new and distinct approach of gamifying music learning. Below is a discussion of a popular theory of gamification, followed by a comparative review of gamification and video games within learning (referred to as game-based learning). Finally, popular game design theories are reviewed which were used throughout the process of developing novel practice tools during the entirety of this doctorate.

2.3.1 Gamification: Yu-Kai Choi

Gamification can be summarised as human-focused rather than function-focused design in that most emphasis is placed on human motivation in the process. For the majority of this research, Chou's definition of gamification (Chou, 2019) is used, in which he breaks the concept into eight core drivers, which he called 'The Octalysis'. Chou noticed that all game techniques vary in how they appeal to players, some inspire and empower whilst others negatively reinforce mechanics. Some drivers were not featured as heavily in the developed solutions, for example, social influences was not a main concept in the developed games because the nature of the games were not suitable and that feedback from primary research (Brett et al., 2021) demonstrated that social influences (mostly leaderboards) would perhaps hinder performance and practice rates by associating negative emotions to play. Below, each point of the eight-point gamification framework which was consulted continuously throughout this research is outlined:

1. Epic Meaning and Calling

Epic meaning and calling essentially describes the emotion a player feels when they have a sense they were chosen to do something only they could do. Ideas such as 'beginners luck', the effect where people believe they have a gift or were lucky to receive a special item or feedback during the game that only they could acquire. It gives players a sense that they are the hero of their own story and are the best player of the game, although in reality of course, this is not exactly true. Earning free items early in game or beating a level which was described as difficult by the developers are some common implementations of this driver.

2. Development and Accomplishment

This driver gives the player a sense of progress and a development of skills which are used to overcome challenges. For example, showing a locked area which can only be opened with a

special ability and forcing the player to progress their skills and return to pass through the area. Within learning applications, this typically takes the form of point systems, leaderboards and earning badges for specific sets of challenges; whilst this is easy to implement, poor design leads to less engagement

3. Empowerment of Creativity and Feedback

This speaks to players who are looking to solve problems in unique ways or repeatedly trying different combinations of techniques to overcome a challenge. This also leads to 'meta game', in which the developer has designed a game with a variety of different solutions or combinations of different skills which can be combined to achieve the best version; leading to players discussing which combination is the best to beat a game quickly or be the most powerful character

4. Ownership and Possession

Giving a sense of ownership to something makes players want to better what they own. This relates to not only accumulating wealth in game but also customization of characters which leads to a more personal relationship. This is what leads to a lot of players using in game currency to customise each aspect of their character – oftentimes leading to a vast amount of real money being spent on something which is not tangible

5. Social Influences and Relatedness

Whilst the most common use is competition and envy (wanting to beat a time in a race or be a stronger character etc.), there are positive social influences also. Mentorship, companionship and acceptance amongst groups are core drivers of play not just virtually but in real scenarios too. It also can be used to help people relate to certain events, emotional and life events – there is a growing body of games which help people deal with major life events such as loss and loneliness

6. Scarcity and Impatience

This focuses on giving players a sense of wanting something because they cannot have it. Games tend to use the 'Appointment Dynamics' (return in so many hours to a reward) – because people cannot have it right away, they tend to obsess about it until they can get it and feel a desire to return as soon as they can access it. It relates to social influences as some players will have an item which other players desire – leading to more engagement as they do not want to miss out (also playing on the concept of FOMO – the fear of missing out)

7. Unpredictability and Curiosity

This is a fairly common trait found in games and play in general. Seeing a big red button elicits curiosity from the players and gets them thinking about what will happen if they press it. This is also true of listening to music and what helps make it satisfying to the listener (not knowing what will come next and then being satisfied or not depending on the outcome). '. . . the very controversial Skinner Box experiments, where an animal irrationally presses a lever frequently because of unpredictable results, are exclusively referring to the core drive of Unpredictability and Curiosity, although many have misunderstood it as the driver behind points, badges, and leader board mechanics in general.'

8. Loss and Avoidance

The idea of losing something after committing a lot of time can be stressful and leads to players investing more time to ensure they do not lose the time invested. This 'Sunk Cost Prison' effect is noticeable in early games which offer few save points or no save points at all, leading to players wanting to keep playing to ensure there invested time and energy does not go to waste. Opportunities which have timers also draw players in to make a fast decision as they do not want to lose a good opportunity whilst it is there – a common example is discounts that last a period of time and get more and more extreme as that time limit gets shorter and shorter

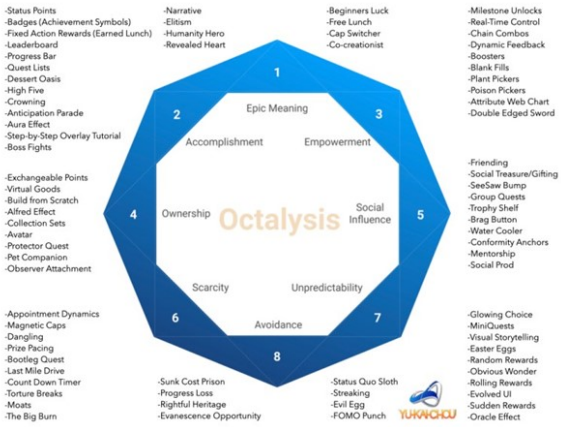


Fig. 2.3 Overview of 'The Octalysis' with Various Additional Drivers (*Octalysis: Complete Gamification Framework - Yu-kai Chou*, n.d.)

The research made use of this framework by analysing existing solutions of similar nature against each of the eight items of the framework and began to pin point specific areas where they were lacking important gamification elements, ensuring that the developed solutions made use of them; mostly assessing learning applications which were popular in the marketplace that faced the issue of high sign ups and high bounce rates.

Regarding new literature and technology, there is evidence to support the fact that gamification can help increase motivation and engagement within this area, for example in Game of Tones (Raymaekers et al., 2014), which showed that participants who used the gamified experience were more motivated and had higher levels of accuracy compared to typical practice. The issue with this study, and others that are similar to this (such as Gomes et al. (2016*a*)) is that they use small sample sizes over short periods of time. However, a key problem is retaining users over longer periods of time with consistent rates of practice. In most cases the typical implementation of gamification is to apply a few elements of gamification to an existing method of learning rather than attempting to tie these elements together into one cohesive experience.

2.3.2 What Is a Video Game?

In order to define novel paths to solving the complex issue this research poses using video games, it is important to define what a video game is and the differences that are found between gamification in learning tools and games positioned around a learning concept. (Esposito, 2005) offers a possible definition for a video game: "A videogame is a game which we play thanks to an audio-visual apparatus and which can be based on a story." (Esposito, 2005) . Specifically, a game is a fictional activity with rules and times which is played without any obligation. Eric Zimmerman defines a game as, "...a voluntary interactive activity, in which one or more players follow rules that constrain their behaviour, enacting an artificial conflict that ends in a quantifiable outcome." (Tekinbas and Zimmerman, 2003). Whilst this definition is satisfactory, one must not forget that there are games that do need in a quantifiable outcome (for example, simulation-based games which are not particularly based on any score). Thus, to play a video game requires movement or decisions which are based on a more rigid structure, "Play is the free space of movement within a more rigid structure. Play exists both because of and also despite the more rigid structures of a system." (Tekinbas and Zimmerman, 2003). The audio-visual apparatus component of a video game is the electronic system of input devices and graphical devices that separate a game from a video game. Finally, whilst story is a typical aspect of game or video game, this is not always the case (once again, taking simulators or even basic playground games as examples). However, there is typically a simulated world in which each video game exists and players find themselves immersed in these worlds and developers of games build rules and restrictions based on these imagined worlds. Using this definition, one can design and develop video games in a more structured approach and use it to make fairer comparisons to solutions which are potentially labelled as 'serious games' but are more based in the ideas of the gamification of a learning tool.

Differences Between Gamification and Game-Based Learning

Gamification, previously defined as applying elements of game theory to an existing learning process is one of the most popular uses of games in serious applications (in this case, learning). Related to musical learning, examples have included learning applications and the use of new technologies to help learners play a piece of music. Outside of musical applications, gamification is seen from fitness to business domains and is a popular 'buzzword' which is often misused or the actual use of gamification in these contexts is poorly implemented. There is another area of research which concerns the use of video games in the context of learning, commonly referred to as Game Based Learning (GBL). GBL uses a game as part of the learning process (or creates new games for this purpose (Al-Azawi et al., 2016)) . "Gamification is turning the learning process as a whole into a game, while GBL is using a game as part of the learning process". Examples of GBL could be the use of Age of Empires to teach players about history or to use Minecraft to teach players about the basic of mining and creating survival tools. Whilst these examples are quite far-fetched, other examples in which games are built for the purposes of training (such as teaching business procedures or even medical procedures) are more grounded for serious applications. Benefits of game-based learning include:

- Problem based solving as opposed to simply telling learners exactly what to do
- Learning through doing which ensures that failure is not frustrating and is beneficial, or even crucial, to progressing
- Offers informative feedback which helps learners correct themselves rather than being told that they simply wrong and how to correct themselves
- Ensures progressive growth which is ideal for goals over long periods of time (such as learning an instrument)

Whilst gamification has been used rather extensively in the field of music learning, this overuse is particularly detrimental. One cannot simply gamify the entire learning process and expect this overhaul of a learning method which has roots in history for centuries, perhaps millennia. Furthermore, literature and commercial solutions which have begun to gamify skill training (notably reading notation and ear training) are adding gamification to existing models of practice, not concerning themselves with the concept of learning-based games. However, in the context of training specific skills which do require repetition, GBL can be a viable and highly useful tool. The idea that a game teaches players specific skills, as well knowledge, is not a new idea; players can retain information on how to execute

certain moves or recall specific map layouts long after they stop playing. Using this passive learning approach found in video games in context to training specific fundamental skills which are required to play key-based instruments is the sole direction of this research. In addition, there is a particular focus on using GBL, in conjunction with other existing video games and game design theory to create a distinct form of GBL which extends beyond the current implementations found in other areas of research. This is the pursuit of developing practice solutions which feel and represent video games and will elicit the same amount of engagement, whilst ensuring that the player passively builds skills which have transferability outside of the game environment to real world applications of their learning.

2.3.3 Game Design Theories

Research was conducted into theories of game design to help gain insight into typical paradigms that are used in games and incorporate some of these into the developed prototype games. In search for a unified list of established principles, 'The 13 Basic Principles of Gameplay Design' (*The 13 Basic Principles of Gameplay Design*, 2009): a 6-point list of principles, with additional facets that can be considered (a total of 12 key lessons to adhere to when designing video games). The purpose of these principles was to help cover all bases when designing video games, referring back to them regularly during development and testing phases. The primary categories are:

- Direction, ensuring the player knows exactly what to do without needing to think about it
- Behaviour, how the player is rewarded or punished based on their actions
- Progression, how to pace the players through the game and allow the player to explore relationships between particular actions (spreading out areas of varying concentration and urgency being important)
- Environment, understanding how to use screen space effectively and communicate space with players
- Method, how to develop your games (ensuring that one lays out each elements of their game rather than extracting elements from a developing random levels)
- Foundation, how do actions affect the player, how are messages communicated to the player and appealing to the target audience

Game Design Documentation and Iterative Game Development

Research was also conducted into theories of the game development process and helped the development of the novel games follow a structure by using typical game design documents and development cycles found in literature (Colby, 2019; Ryan, 1999) as well as in marketplace games. In this case, this was via adopting a rigorous iterative cycle of small development periods and substantial amounts of user testing, which some would argue is key to developing games of a novel nature (*Better Games Through Usability Evaluation and Testing*, 2005; Mirza-Babaei et al., 2016). The reason for this development method was to ensure avoiding over developing a concept which had little merit and that the established reasoning for developing such prototypes was established by the key demographic. Not only this, but it was important to the development process to reach out to those outside of the design and development team rather than falling into the common pitfall of designing games that were playable only by the developers. The research also considered Fullerton's mode of iterative game design (Denham, 2016) which is made up of distinct phases: concept, pre-production, production and quality assurance (which loops in specific areas until a well-rounded product has been developed).

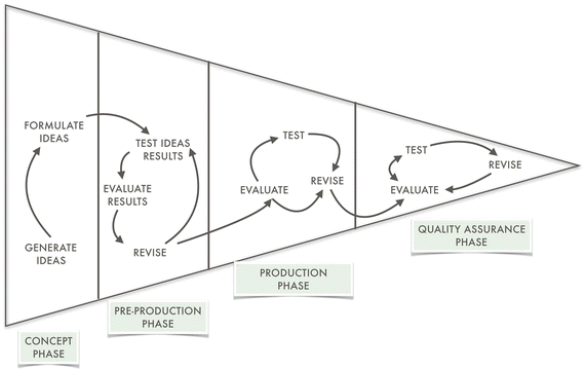


Fig. 2.4 Fullerton's Model of Iterative Game Production (Denham, 2016)

Juice

Other video game design paradigms revolved around behaviour, by ensuring players were rewarded for correct actions and reinforcing this with additional 'juice' (Hicks et al., 2019). 'Juice' is a relatively newer terminology to consider when developing games and refers to the visuals and audio feedback that games provide to players, for example, adding sounds on particular actions such as jumping or a muzzle flash when a player fires a weapon in a shooting game. Hicks et al. (2019) conducted an experiment to determine the effects of juiciness compared to typical gamified experiences; results showed that the participants

using the exercise which had both elements of gamification and juiciness scored the highest compared to those that had just the gamified version. Each game incorporated additional layers of design to reiterate particular mechanics and rewards throughout but it was important to pay close attention to the previous lesson in not over developing; striking a balance between having enough feedback for the players and not over investing time into design was tricky but important.

Gameplay Loops

When designing games, serious consideration must be made to the loops that define the game and how feedback is handled. The core loop (Core Loop in Game Development - The Knights of Unity, n.d.; Crook, 2012; Momoda, 2013), an established game design element, is the basic mechanic that the player does repeatedly within a game; it should be relatively simple and consist of distinctive elements. Examples include: navigating a maze to collect dots and avoid ghosts or firing projectiles at enemy ships whilst avoiding being shot; examples are not just apparent in video games but extend to every game.

Whilst the core loop is intended to be simplistic, the mastering of the action is what drives engagement within games. Using the Pacman example, if one follows a specific path or becomes adept at predicting the move patterns of the ghosts, they will become masters (this also refers to 'meta game' (Costiuc, 2019) in which players define the best combinations of play styles to be the best at the game). Adding depth to a games core loop is essential in it being engaging and unique. The idea behind loops is that a user will play through one session, collect resources or improve their skill(s) during play and return to play with this new knowledge or resource in order to improve their overall play experience.

Flow and Difficulty

Literature relating to flow (Chen, 2007) was consulted; to ensure that players do not get overly frustrated, difficulty must be increased exponentially whilst also allowing players to take a break and feel as though their progress is impactful. Occasionally referred to as the 'Nishikado motion' (who helped define the difficulty curve by accident during the development of Space Invaders) or a 'series of ascending arcs' (Holleman, 2019). This regular up and down motion of a games difficulty ensures that the player feels as though the game is progressing but does not feel overwhelmed with a constant increase in difficulty. Powerups are a common way to instil this effect and can help players feel as though they are getting lucky at the right moment, playing on the Epic Meaning and Calling driver of gamification (Chou, 2019). Striking the balance of rewarding players with easier sections

and increasing difficulty gradually was key when developing a game for the purposes of practice, as too little reward will lead to a lack of fulfilment whereas, on the other hand, too much punishment would lead to frustration and not wanting to return.

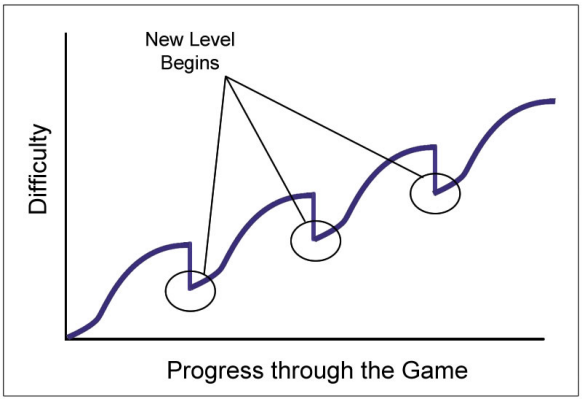


Fig. 2.5 Implementing difficulty using 'A Series of Ascending Arcs' (Holleman, 2019)

2.4 Conclusion

This literature review has highlighted one of the main reasons for adult beginner keyboardists, particularly those who learn in an independent and casual capacity, to drop out early from their learning is the lack of fundamental skills as well the frustration between a lack of effect to the significant amount of effort required. As stressed by many beginners, from literature, primary research and personal reflections, one of the core outcomes or desires that such learners have when playing keyboard is the ability to play unfamiliar pieces of music in a fluid manner. This outcome is constantly out the grasp of such learners when they possess few to no musical skills, and are met with further frustration when consistent hard work never seems to pay off. Whilst the keyboard is considered an incredibly popular choice of instrument for first time learners, the learning journey and curve is not a short one and requires copious amounts of commitment and dedication; this in conjunction with no engaging medium to practice typically leads to such learners dropping out early. Utilising frameworks of musicianship, specific skills were targeted in which novel game-based learning solutions could be most effective. By defining particular user and learner groups, these game-based solutions would also have a particular demographic in mind, ensuring that the proposed developments would be able to offer transferable skills which can have real-world long-term effects.

The second portion of the literature review was directly analogous with the second research topic, video games. A specific framework was outlined for gamification which would

later be called upon when designing the practice games; the review of how gamification is used within the research and the commercial worlds helped to highlight the poor implementation of gamification as well show that gamification is perhaps not the entire solution to gamifying learning and practice. This difference was explored in depth as a definition of game-based learning was offered. As the next chapter explores, most, if not all solutions for this issue simply consider gamification as an after thought and never utilise game-based learning for their learning or practice solutions. As a result, the research began to utilise game-based learning to help develop novel practice solutions in the form of video games. To ensure that effective concepts were developed, an evaluation of game design theories was required, in which the final section of this review was used for. This particular review helped to define the key theories that were used in the development of novel practice games and helped to ensure that they were as engaging as possible; in an attempt to define a distinct form of practice with which the idea was to eventually replace other recreational activities such as playing video games, with such concepts.

The next chapter, the preliminary research, offers a systematic review of the existing solutions found in the literature and the marketplace that help solve this issue. Using the research of video games, specific concerns are outlined and eventually led to the discovery of the gap in the knowledge: a lack of solutions that utilised game-based learning for meaningful practice that would help to acquire skills applicable to real-world applications. The final section of the preliminary research discusses the initial concepts that were developed in an attempt to build such learning-based games; this development cycle helped to build the foundation of the entire future of this doctorate and led to novel artifacts in the form of games and assessment methods.

Chapter 3

Preliminary Research

3.1 Chapter Introduction

The literature review had helped to define the key areas of learning and playing keyboard which were typically associated with tedium and require rote learning, but were imperative to building a strong foundation and ensuring continuation of the learning journey. The review had also provided the main theories of gamification and game design with which the novel solutions that would be developed would be founded upon. It was also important to review how other researchers and developers had attempted to solve this issue of high drop off rates exhibited by adult casual keyboard beginners, so one could begin to understand why they do not offer the tools for such learners to continue their learning past the beginning stages. The final research topic is that of existing solutions which is explored through this chapter. A review of the literature is presented that shows similar issues as well as other solutions to the key issue: mostly concerning the rolling-note style method of learning to play a musical piece, learning applications and solutions particularly focused on improving or helping to acquire musical skills. The solutions reviewed revealed a gap in the literature between video games and serious practice of the aforementioned fundamental skills; leading to the developmental journey of this research's novel game-based learning approach to practice that offers meaningful transferability of fundamental skills in regard to keyboard education.

To help define novel solutions and an original philosophical approach to solving the complex issue of high drop outs regarding beginner keyboardists/pianists, multiple games and gamified training tools were developed. This doctorate initially begun by developing VR and AR prototypes for music creation uses. Most of the solutions were either played from a seated position in which a musical instrument was the main focus or from standing in which the player made use of the space. Some of these concepts were founded on existing games (*Audioshield*, 2016; *Beat Saber*, 2019) but with the unique twist of incorporating ROLIs

products, such as the Lightpad M (*Lightpad Block Studio Edition*, 2018) where players could hold down parts of the musical pad to create visuals within a virtual space. 'Groove kits' were used which were predefined loops and sounds that were created by ROLI. By holding down particular areas of a pad, loops could be created, along with abstract visuals, and then players could switch to drum set kits or lead sounds (such as an electric guitar or unique synthesiser sounds) to overlay on top of the pre-defined loops – giving them a sense they were creating their own songs from a few basic loops.

Through consulting literature, canvasing learners of all skills levels and based on personal experiences, it was also apparent that learners wanted to learn existing pieces of music which they can draw upon for their music creation and to play for friends and family. As mentioned later, the Leap Motion was incorporated (Sharma et al., 2018) to help users track their hands in virtual space and used a 'virtual keyboard' which was a 3D model of a keyboard, later the LUMI. The idea was to eventually have this connect to a real tutor or, with a lot more research, an AI tutor which could be seen as a virtual avatar - increasing accessibility and ease of use for in person lessons became even more relevant during the Covid-19 epidemic.

This chapter outlines the main existing solutions that were consulted which showed a poor implementation of gamification and a lack of game-based learning regarding keyboard practice; not only this, but the assessment of existing solutions rarely consider the real-world applications of their developments. The chapter also discusses the development of the LUMI and the consequent mini games that were used for practice alongside or within the application. An in-depth review of the games is delineated in which limitations of using VR and AR are discussed. Finally, the key limitation of poor assessment methods and a lack of organisation is discussed; this limitation led to the first set of developed mini games which had some form of structure. Not only this, but this was a first step towards creating a robust assessment method to ensure validity of these novel games in real world contexts as well as the emergence of a framework for designing and developing such tools, in which important principles and repositories are shared for future developers and researchers alike.

3.2 Existing Solutions

This section covers the various existing solutions, presented in both the literature and found in commercial use, which have attempted to solve or help aid solutions to the key research problem. A discussion and critical review of 'rolling style' notation as well learning applications followed which helps lead to the solution in the form of specific gamified practice solutions targeting specific skills. Finally, a review of the solutions which are specifically tailored to help practice fundamental skills (as this research is also attempting) is conducted.

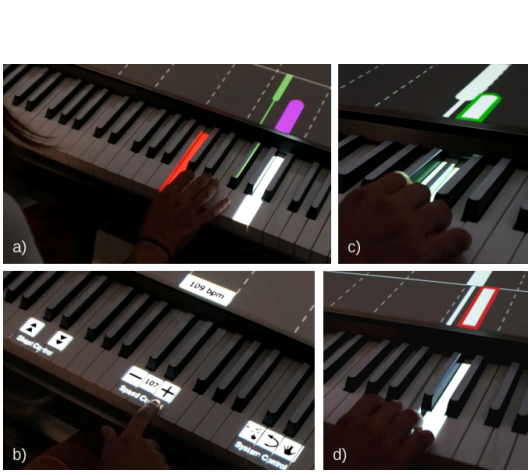
This is where a significant gap in this research is found – a lack of game-based learning and the correct use of gamification and game design to help create engaging games that offer meaningful transferability to real-world applications for adult beginners.

3.2.1 Rolling Note Style and New Technology

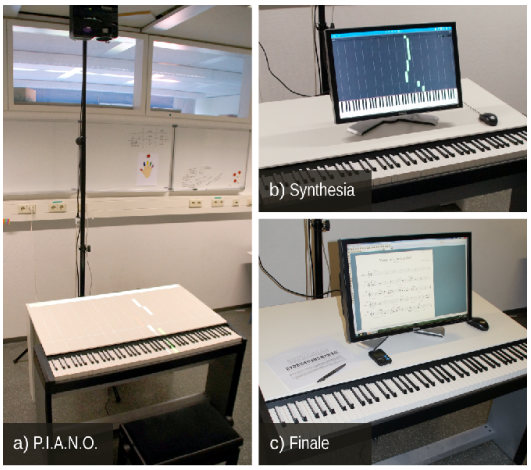
As highlighted by the desires of the particular demographic this research is targeting, novices and lapsers, learning to play a piece of music was paramount. Whilst traditionally, one would study reading musical notation and learn to play a piece by reading it's notation, modern solutions have attempted to reduce the cognitive load and stress of this task by digitalising reading music. This typically takes the form of a 'rolling note' style graphic in which learners simply hit the keys when instructed or follow lights on a keyboard (made popular by (*CASIO*, 2020)).

Methods found in literature attempt to teach people how to play pieces on the piano using gamified AR. One such method of teaching piano basics was developed by Rogers et al. (2014). Graphical notation is projected on a board in front of a piano that indicates which key(s) need to be pressed and creates a feedback loop to monitor user performances. Findings were positive and confirmed that performances of P.I.A.N.O. learners achieved higher overall impression and perceived quality of practice. Learning with P.I.A.N.O. resulted in less negative intrinsic and extrinsic cognitive load, more positive germane cognitive load, and provided a better user experience. However, the issue here is that learners become reliant on a new system of reading music whilst the rest of the learning journey will, eventually, use sheet music. On top of this, the short time frames in which the studies were conducted do not give insights into how or indeed if the system would help motivate leaners to practice on a consistent basis nor whether the skills acquired through the system are applicable to other areas of keyboard playing and learning.

A very similar implementation was also developed by Raymaekers et al. (2014) in which graphical music notation was displayed onto a surface using a projector in a 'scrolling note' fashion. The authors extended the augmented piano with a shooting game using the same system to help encourage users to continue playing through the use of game-based incentives. The reception was positive and gained a lot of attention (audience members were attracted by a highly graphical and musical demo). But the issue still remains from the other similar implementation and the feedback reiterates this: '. . . the notation seemed confusing for certain experienced pianists who expressed they would not want to use it for pieces that they already know.' For the beginners, the system was slowed down as they could not keep up and this shows that the system is limited – one cannot simply follow a series of actions and expect to it to sound like a sonata. The basics of reading music and determining tones by ear



(a) The 'P.I.A.N.O' system in action



(b) The 'P.I.A.N.O' system used in testing with 'Finale' and 'Synthesia' as comparison applications

Fig. 3.1 The P.I.A.N.O system overview and used in a study; the issue with comparing a solution which uses notation to a solution which is simply to follow along is the uneven playing field (Rogers et al., 2014)

are clearly skills that are required to master musical pieces and solutions such as this one do not convey the depth that a musical piece may have. The positives of this solution, however, were that beginners were more likely to practice using a gamified approach.

Perhaps the most feasible solutions make use of VR or AR headsets. The 'HoloKeys' (Hackl and Anthes, n.d.) uses a similar setup as the projector solutions but instead presents the view through an AR headset, allowing learners to practice on any keyboard or piano without having to setup further hardware. Most solutions that use AR follow a similar pattern of displaying a rolling style of notes which lead to each key where the player must play in time. When these solutions were first reviewed, the negatives were the cost and how the headsets were not robust enough to handle a large field of view and complex hand tracking which allows for assessment of individual fingers. However, during the course of this doctorate, there have been a number of advancements in the field of AR, particularly the Oculus Quest line of products (*Meta Quest 2*, 2020). More recent market place developments (*PianoVision*, 2022) make waves for this style of learning and can offer a better approach to learning to play musical pieces in this fashion. However, one must still remember the core issues of learning this way. One cannot simply follow a series of actions and expect to convey the depth a piece of music offers. The nuances of how individual notes are played, the emotion that is conveyed in each note offered in a single piece and how the individual parts become perfectly integrated into the entire composition cannot be imitated by following individual notes one by one; just as a conversation is not a string of the same tones but has

depth and layers. Not only this, but by attempting to simply play notes in an order without consideration to other musical attributes can lead to poor form and future issues with playing.

3.2.2 Market Research

To gain an understanding of the breadth of the musical applications on the market, a systematic review of popular music applications was conducted to help decipher why users disengage quickly with them and how game-based solutions could help fill the gap (or at least help to further research and development into extending learning of adult beginners). Each application was reviewed based on five core concepts of the definition which was believed to be most appropriate for the core goal. These were: amount of enjoyment, using Fu et al. (2009)'s definition which comprises of concentration, immersion, goal clarity, challenge and feedback; also using theories of flow (Chen, 2007; Johnson et al., 2018). The other criteria included pedagogical value (i.e., how much each application offered to a beginners learning and how meaningful it was to real-world applications), skill required (how versed a user needed to be with the software or application to use and understand it), complexity (i.e., usability) and time spent (i.e., how much time was needed to be spent to learn something valuable). The reviewed applications fit into specific categories and are designed to cater to various types of users. These categories were: professional, educational, and gaming. Professional applications included DAWs and synthesisers which offered little educational value and were used by specific individuals who were prosumers and not casual learners. Educational applications were essentially designed to be educational and teach users a specific instrument, music theory or how to create music. Finally, gaming applications were games which had a heavy feature of music or were rhythm-based; whilst they focused on music, they offered little to serious learning.

Professional applications were not suitable for the purposes of learning and few lessons would be gained in reviewing them further. The music games that were reviewed, in which a full list is made available in the Appendix, were highly enjoyable and played by a large audience but lacked little, if any, educational value. The 'musical learning applications' that were reviewed (Eli, 2016) are designed to try and meet the needs of each one of the core concepts outlined. The history of this style of learning is rather old and originally took the form of CDs which could be on a PC. These solutions comprise of a series of lessons, typically a tutor would deliver learning content whilst demonstrating this on a piano with the inclusions of specific pieces to practice, and the student follows along each lesson and progress over time. In the modern day, with the use of mobile devices, this style of teaching has been adopted in mobile application form. The concept stays relatively the same in that a series of lessons are followed by a learner, albeit, with more complexity by incorporating

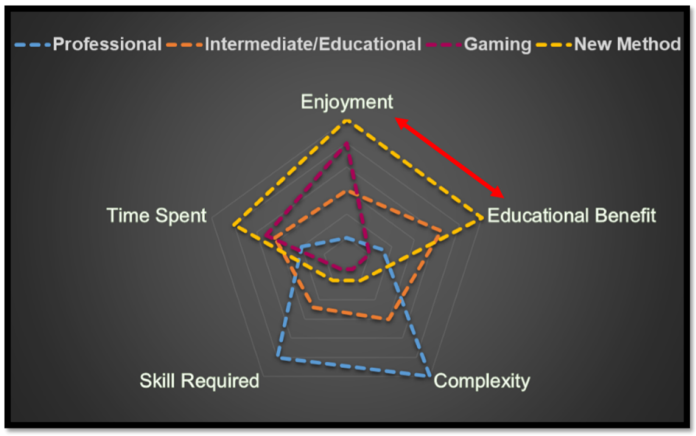


Fig. 3.2 The five key points of assessment: the solutions should cater to all criteria with a focus on educational benefits and enjoyment or engagement

gamification (leaderboards, badges and points). Whilst these learning applications do offer rich learning in the form of lessons and interactive exercises, the problem still persists, as learners struggle to get past a certain point because they lack either the skill or knowledge to do so. They essentially ensure the first few hours are interesting and rewarding for the user by offering them simple tasks which provide high reward with low cost but once a certain point is reached, users lose interest and begin to feel frustrated as either the applications' content becomes too difficult, or remains too easy and lacks gratification. A final issue that was discovered with learning applications was their target demographic. Typically games, and generally any other software tools, are developed with a specific demographic in mind and will typically run user testing with these audiences to ensure that they will be able to retain them with specific design and mechanic choices. As the learning applications attempt to appeal to such wide audiences, it makes it difficult to pin point a specific target demographic, thus leading to difficulty in retaining any audience at all (as highlighted by (Bobbe et al., 2021)).

3.2.3 Solutions Tailored For Skill Acquisition

When learners want to practice specific skills or revise particular knowledge, the learning applications offer easier lessons which lack any progress for the learner or simple and somewhat mundane exercises. Other existing tools found on the marketplace and in literature, mostly ear, rhythm and sight-reading trainers (*ABRSM:*, n.d.; *Musicate*, n.d.; Pesek et al., 2020; *ToneGym: Ear Training*, 2018), can be used in conjunction with other learning methods to help practice specific skills and vary from purely functional trainers to more gamified approaches. However, for the most part, the gamified trainers do not consider gamification

from the beginning of the design process and simply 'add-on' elements of game design, a lot of time in the form of leaderboards and levelling systems, then call their approaches gamified learning. Whilst these training applications do work for more serious learners (as they are already passionate about and confident with learning their instruments), the more casual and independent learners grow quickly bored and uninspired to return. There is a lack of solutions in this area of research and the marketplace which attempts to merge a video game experience with meaningful practice; this approach has been established in other areas of rote learning, most notably the practice of typing on a physical computer keyboard (*Epistory - Typing Chronicles*, 2016; **?**).

Literature Examples and New Technologies

There are some particular use cases of training tools that make use of gamified learning in some capacity within research. Typically, these solutions focus on three key skillsets: ear training (audiation), rhythm or reading notation (often labelled as 'sight-reading trainers'). One such example is Troubadour (Pesek et al., 2020), a gamified platform for ear training purposes. The platform was developed to support music theory classes at music conservatories. Essentially, the application is a series of ear training exercises displayed in a graphical and colourful fashion. The gamification includes achievements, badges and a progressive skill level which can be compared to other students on the application (using leaderboards). Whilst the use of gamification is substantial, this had little effect on the longevity of the use of the application; participants rarely played the game for more than a day or so at a time and whilst they would recommend to other learners, this was in the context of an academic setting (not representative of casual learners). There is a lack of solutions that cater to casual learners, as most research (Wang, 2022*a*) focuses on existing students who are already enrolled in a school. Furthermore, the literature that was found is particularly concerned with younger audiences, typically those who are in primary or secondary school, with a lack of research for motivating adults using gamified tools. Thus, there is a gap in the literature which dedicates itself to using game-based learning to increase the rate of practice, helping to lower the dropout rates observed, in particular concern to adult, independent and casual beginner keyboardists.

3.3 LUMI Emerges

Whilst VR and AR allowed helped to create novel solutions for helping to play musical pieces or even for the sake of pure enjoyment in regard to music education, it was apparent that it would not be a particularly viable avenue due to inaccessibility of both cost and

setup whilst also not fitting the company's ecosystem – offering rather complex solutions to absolute beginners was not a great method to increase onboarding rates. Based on these limitations and insights, which pointed towards beginners desires to play musical pieces more than create their own music, the company pivoted to creating combined hardware and software solutions that targeted purely mobile devices – eventually developing the LUMI (*LUMI - The World's First All-In-One Platform For Learning Music At Home | LUMI*, n.d.) and consequent learning application also dubbed LUMI. The LUMI Keys is a 2-octave range MIDI keyboard in which the keys can be fully illuminated with any RGB colour. The keyboard uses DNA connectors (*What is a DNA connector*, 2018) which allows for multiple LUMIs to be connected to one another or any of the BLOCKS ecosystem. The keyboard offers per-key pitch bend and polyphonic aftertouch. It connects to any operating system using either USB or Bluetooth, in which the primary use was to connect it wirelessly to mobile devices which would run the LUMI learning companion application. The LUMI application is a suite of lessons and practice tools whilst also offering the rolling note style of playing. The application is one of the most graphical designs in this area and attempts to push the boundaries where other learning applications had not. The software and hardware combination is quite rare and is a somewhat novel approach to learning keyboard and whilst other keyboards and electric pianos had used light up keys to assist learning (*The ONE*, 2019), LUMI was the first to make use of fully illuminated keys in any colour – using equivalence based learning theories to help reinforce the relationship between colour and sound.

However, the key issue still remained that beginner learners will eventually taper off and it was established already that the method of learning to play songs by following lights or actions was not ideal. The LUMI ecosystem was designed to make onboarding more approachable and easier for beginner keyboard learners but eventually would teach them how to play musical pieces purely from sheet music – the light up keys and rolling notation were simply a way to entice learners and increase their onboarding satisfaction. Combining the research issue of high amounts of beginner drop off with the need to increase retention within the LUMI application, practice games were developed which would either work alongside or within the application; the hope was to create a platform of practice that would encourage learners to persist beyond the beginning stages of their learning journey and return to the learning application. The games were considered as either a reward for learners who had completed a lesson or a song whilst also being a way to reinforce particular skills and knowledge related to their recent lessons, for example, a practice game that could help reinforce the relationship between a physical key and the name of a specific note (later relating this to a note on a musical staff).

Fig. 3.3 The 'LUMI' specification used in the Kickstarter campaign

Fig. 3.4 The 'LUMI' keyboard and companion learning application in which a user plays through a song using 'rolling notes'

3.3.1 Practice Games Using New Technology For The LUMI Application

The developments began by looking towards using VR and AR for the purposes of practice alongside the LUMI learning application. Although limitations were considered, it was deemed more appropriate to build VR/AR practice games and tools as it was not the sole hardware beginners would purchase but an add-on that could make use of learners who already had access to VR technology. Furthermore, it would help the LUMI system stand out amongst the many other learning tools and software that were already found in the marketplace – at the current state of writing, there was nothing similar to be found in the marketplace at this stage. A small selection of practice games using mostly VR hardware were developed with additional investigations into how AR could be used, and the potential it had for future iterations. Using the research's definition of musicianship, specific skills were chosen to build practice games around. These included practicing reading basic notation, basic rhythms, recognising pitches and patterns (audiation) as well as executive functioning skills, mostly relating to hand and finger skills.

For the most part, the HTC Vive was used (*VIVE*, 2016) for the VR prototypes whilst later developing for the Oculus Rift (*Meta Quest 2*, 2020). The HTC Vive was chosen as it is considered somewhat of the 'gold standard' for VR and its capabilities did not limit ideas, allowing development of what was deemed appropriate for this level of research. The

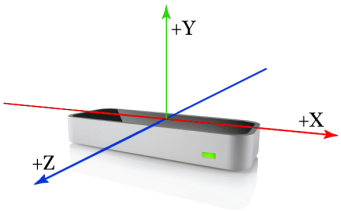
Oculus was later used for portability and cost related reasons - being a lot more accessible, not requiring a high-performance PC to run and considerably cheaper meant it was a lot more appealing to the target population. All of the VR and AR prototypes were developed using the Unity Engine with C#. For the AR solutions, a Microsoft HoloLens was used (*HoloLens*, 2016), which had also been used in other research (Rigby et al., 2020), mostly because it was one of the few AR headsets which had the capability required – a high enough field of view and the ability to run third-party developed applications. The majority of the AR headsets were not nearly as robust and their lack of documentation meant it was incredibly tricky to develop for. The exploration of AR solutions was only on a surface level as the technology was not advanced enough at the time to actually develop meaningful and market standard games or applications.

A notable mention was a VR game which intended to help beginners improve their overall sense of rhythm and understand different styles of rhythm found across genres. The game was inspired by other rhythm games which were developed for VR, specifically, *Beat Saber* and *Audioshield*. There were discussions around whether or not this research should focus solely on the development of rhythmic skills for beginners and consider using pre-existing video games and the custom solutions to determine how useful they would be for real world applications of playing keyboard and piano; future chapters delve into why this option was not chosen for this research and why the choice to investigate reading musical notation was investigated instead. The game placed learners within a graphical tunnel in which animations flashed to the beat; blocks would spawn from the start of the tunnel and move towards the player where the player had to smash them with their controllers or hands. The difference in this game and the market place ones was that there was a focus on specific rhythms, for example, 4-4 time which was believed to have more real-world application to playing keyboard and piano.

Using VR and motion controllers was an insightful endeavour but there was a desire to incorporate the LUMI into the solutions, considering that these practice games were supposedly working alongside with the LUMI ecosystem. Therefore, the Leap Motion (Sharma et al., 2018) was implemented to develop further solutions which were adopted from similar literature (Das et al., 2017). In his work, a HoloLens is used in conjunction with a Leap Motion in which graphical notation is displayed and players can use their hands to play physical keys when the note visuals approach the specific keys. Whilst his work was novel, there were limitations, which include the accessibility of this hardware to a greater audience as well as real world applications of such technologies.

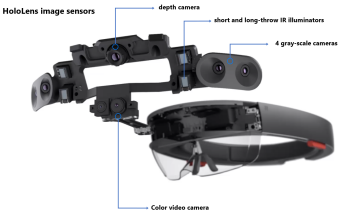
There was a desire to extend these solutions and attempt to track induvial fingers in which an AI system could watch and teach learners what fingers and hand shapes were most

Fig. 3.5 'Ultra ROLI', a VR rhythm game in which players must hit blocks using motion controllers to a set tempo and time signature (in this case, 4-4 time)



(a) The Leap Motion

(b) Leap Motion hand orientation demonstration



(c) The Microsoft HoloLens

Fig. 3.6 Various hardware which was used for the AR and VR developed solutions

appropriate for specific parts of songs. Tracking whole hands was easy but the Leap Motion was not robust enough to track individual fingers on a level of specificity that was required, not only this but it was difficult to get the hand tracking consistent when playing – often losing tracking altogether. Later, a developed solution manged to track the LUMI within a virtual space using Vive trackers (*VIVE Tracker (3.0)*, 2020), which are physical trackers that can be attached to objects to track their position and orientation in real time. The solution tracked the hands above the keyboard so users could feel a physical keyboard and also see it in real time within the virtual world; a key issue that was discovered with VR solutions was the lack of tactile feedback as most solutions used virtual instruments.

3.3.2 Limitations Of New Technology

AR was, and still is, an emerging technology and at the time, suited more industrial solutions. Recent developments (*PianoVision*, 2022) have increased the potential for this technology to

be used in more pedagogical contexts but the issue of real-world and meaningful relatedness to learners is still questionable. VR, whilst innovative and more financially accessible, had a key drawback: hand and physical model tracking. This drawback meant that most of the learning had to be virtual and any physical learning was limited – the learners could not see nor feel the actual physical instrument they were playing. When incorporating hand tracking technologies, such as the Leap Motion, the actual VR headset required to run alongside had to be rather advanced, therefore expensive, and the hand tracking itself was not robust enough for individual finger tracking. When attempting to track a physical object within VR alongside rudimentary hand tracking, tracking required additional hardware and would often fall out of vision of the cameras attached to any given VR headset. However, a key limitation of these solutions was accessibility, in regard to both cost and ease of use. Few beginners will spend much on their first instrument, let alone spending more on VR technology to practice something rather basic. Relying only on learners who already owned such technology limited the approach too much. It became apparent that the technology at the time was not advanced enough to offer a meaningful solution to the issue and the research began to look into solutions which did not solely rely on VR or AR.

3.3.3 Mobile Practice Games For The LUMI Application

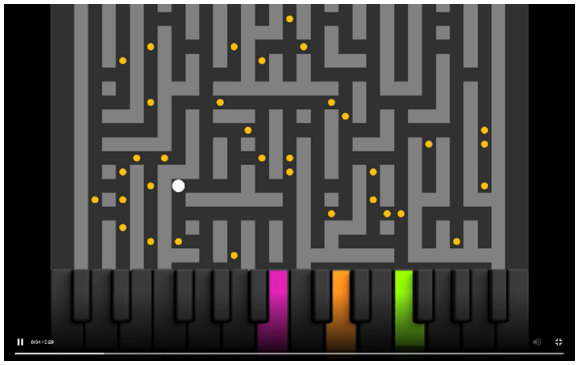
Based on the limitations of VR and AR prototypes, there was serious considerations to what practice games would be suitable to work within or alongside LUMI which would work on predominantly mobile devices. The prototypes needed to incorporate music, a pedagogical component and resemble a video game, striking a balance between all three gave way to a plethora of ideas. Working alongside the lead game developer at ROLI, a multitude of mini games, ranging from simple flash card style guessing games to games which replicated existing ones but would be played with the LUMI or required a particular skill to execute a mechanic were developed.

The developed solutions included games that would help learners practice reading musical notation using a ‘Space Invaders’ style of gameplay where notation and note names fall from the top of the screen and must be destroyed before reaching the bottom. A game was developed which required knowledge of scales where players could fire down lanes corresponding to notes in a scale to destroy incoming hazards. There were ideas which revolved around the use of particular hand positions, working with triads, to navigate through a maze, resembling the style of ‘Pacman’. There was a huge bank of game ideas, many of which are not mentioned here but the entire list of ideas is made available and is accessible in the appendix.

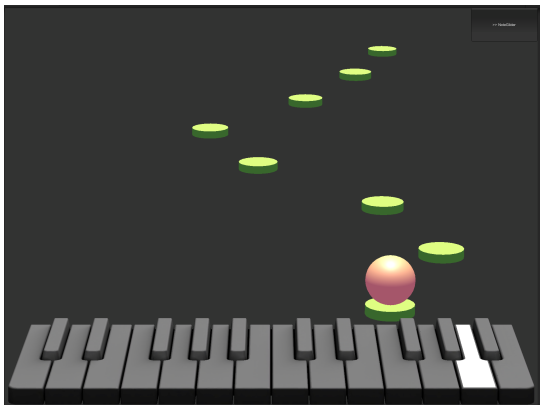
Fig. 3.7 An early concept of 'Superluminal' a game which is played using notes of a scale to navigate through space

3.3.4 Development Which Lacked Validation

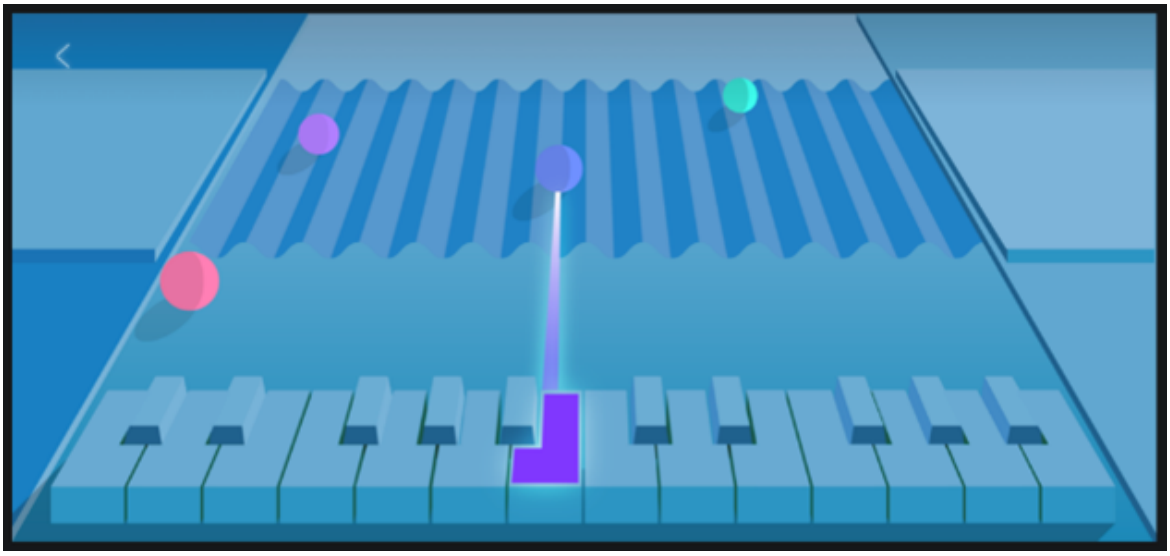
Whilst the research begun to open new doors into the realms of novel approaches to gamified practice, it was clear that these solutions needed more scope to avoid over developing and never reaching any concrete conclusions. Some of the developed games would perhaps be highly pedagogical but may lack any sense of game design or gamification, whilst some concepts would be the opposite and could be highly engaging but not particularly educational in context to the key leaner groups. Whilst there was an ability to discover new ideas and prototype them rapidly, they were only being tested internally and the games were only being played from the perspective of developers and designers. What was required was a model of assessment which could be built upon and use to create an iterative flow of design, develop and test. Not all the games could be taken forward so there was a key decision to build a small suite of mini games to begin the first round of assessment. What was required was a range of games from the least gamified and most pedagogical to the opposite of this spectrum; this would help define the fine balance between video game and pedagogical value, whilst ensuring that all games featured music at their foundation.



(a) ‘Maze Runner’ a practice game which uses triads to navigate through a maze



(b) ‘Note Jump’ by playing notes the ‘player’ jumps from one platform to the next



(c) ‘Scale Shooter’, another practice game which helps learners recall specific scales

Fig. 3.8 Various practice games developed for the LUMI application

3.4 Chapter Conclusion

Whilst a significant proportion of the literature, as well as solutions found in the marketplace, attempt to replace the traditional style of learning to play a piece of music (i.e., sheet music), these solutions are not adequate; they often lead to poorer form when playing, do not reflect the depth and expression of a piece of music and have a lack of application outside of this play style. More recent solutions that attempt to gamify the whole process of the learning journey with the use of mobile applications (i.e., music learning applications) have helped to increase accessibility and portability of learning. However, these solutions help to inspire beginners to start their journey but there is seldom research or efforts made to help ensure

the longevity of a learners journey is ensured, typically leading to frustration or boredom and eventual drop out.

A more appropriate use of digital technology is increasing motivation in areas of learning that are imperative, but also associated with tedium. Thus, the belief of this research is that video games are best as a supporting aid to a learners journey; this approach attempts to ensure that the learning journey is never abandoned. Whilst there is some research in this field, which specifically focuses on rhythm, ear and notation reading (or sight-reading training), these solutions attempt to add gamification to existing learning tools or methods. Not only this, but the methods of assessment of all the solutions found were on a surface level; they helped to ensure that a learner improved within their developed solutions but never explored how this could transfer to real-world applications of learning, particularly over long periods of time.

From these findings there appeared to be a gap in the research of music learning, specifically concerning key-based instruments, in which the use of game-based learning could be used for the purposes of meaningful practice. This research explores a somewhat novel approach to music learning in conjunction with video games, whilst offering novel methods of assessment. The sole purpose was to ensure that such solutions could have meaningful transferability and real-world applications which would help to increase the longevity of independent adult beginner keyboardists.

To this end, various gamified solutions were developed in pursuit of attempting to merge game-based learning with meaningful practice. The literature review established that using new technology or the 'rolling-note' style of learning to play a piece of music would cause further complexity or shortcut techniques that would lead to poorer performance and be detrimental to future playing and learning. Therefore, a host of mini games was developed with the goal to improve specific fundamental skills that can increase the quality of learning and playing of a piece of music. However, there was a lack of specificity, organisation and no tangible way to assess such games in this pursuit during the first cycle of development. A framework of design, development and assessment was required if such novel concepts were to be developed in a meaningful way. In the next chapter, the first round of mini games which had some of form of structure is discussed, focusing on the development of such games and includes the first round of assessment which is improved upon throughout this research.

Chapter 4

Developing Games For Rote Learning

4.1 Chapter Introduction

Previously discussed, the initial prototypes were developed for the purposes of music creation in conjunction with various HCI technologies and mediums such as VR and AR. During this stage, the placement company were seeking new ideas to promote the joy of making music and to lower the barrier of entry of creating music; attempting to become the 'Guitar Hero' (Hemingway, n.d.) for keyboard and piano, albeit, with newer technology. Small prototypes were developed using the HTC Vive (*VIVE*, 2016), the PSVR (*PlayStation VR*, 2018) as well as looking into AR, mostly with the Microsoft HoloLens (Taylor, 2016). Based on the limitations mentioned previously with VR and AR pursuits (inaccessibility and complexity), the placement company began to develop a roadmap which focused on keyboard and piano education from a more classical perspective, rather than the creation of music itself. The goals for this solution would be to create a graphical and engaging way to learn pieces of music which range from the classical to modern, to teach beginner keyboardists and pianists the basics of playing their instrument whilst also introducing them to the more traditional side of keyboard and piano, delving into reading music and the typical tropes one would expect to find from any given teacher or traditional book, such as (Palmer et al., 2005).

As previously discussed, the final product that emerged from this stage was the LUMI and the companion learning application with the same name in which mini games that would help practice specific, foundational skills were developed to work within and alongside the application. The list of ideas was rather endless and different prototypes were developed on a regular basis. However, there was no method of assessment and no cycle of iterative development which leads to an idea which has true merit. Therefore, a suite of games was developed which would follow a cycle of development and testing, ranging from more traditional practice to novel gamified approaches, in order to help determine the balance

between video game and meaningful practice whilst also determining the ideal games which would fit into the LUMI ecosystem most naturally.

This chapter goes into the details of the suite of mini games that was created, which offers an in-depth report of the various prototypes made during this stage. The overall development process and pipeline is discussed, whilst mentioning key pitfalls to avoid and design principles to adhere to. This is followed by a discussion on the first study which was conducted to assess the mini games and to determine an ideal audience, narrowing in on how to assess the validity of these games regarding their engagement and educational impact. The findings are reviewed which helped give further direction to the research and why this path was taken based on the first year of this doctorate.

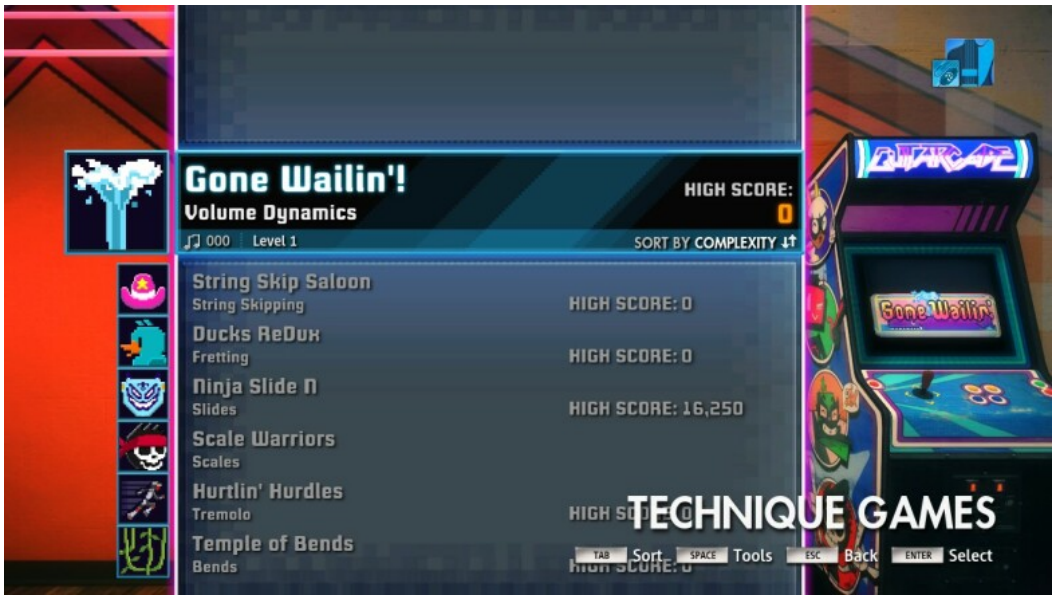
4.2 Developing the Mini Games

Each mini game was developed so that the core mechanics were driven by the learning component (e.g. practicing scales can be used to drive the mechanics for a game where playing corresponding notes destroys enemies); these learning components are derived from the pre-defined set of skills which require rote learning. Drawing upon paradigms from gamification, game theory and current applications on the market, the games to be original in their nature whilst also create an engaging environment for practice. Design considerations for each game are discussed and what is believed to be the negative and positive aspects of each, in hope that others will be able to take the imparted knowledge and build upon this to create their own novel experiences.

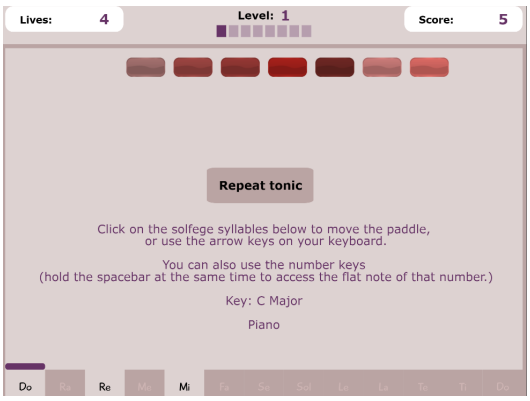
4.2.1 Inspirations

Developing each game was typically supported by borrowing ideas or designs from existing games or learning tools, whilst also adhering closely to the game design principles that were established. For this suite of mini games, ideas were borrowed from existing learning games such as those found in classrooms, which included simple flash card and 'repeat after me' style games as well those on the web (Colin, 2016; *Theta Music Trainer*, n.d.). The concept of developing a host of small games inside an existing platform (the LUMI application) was based on the concept where other games implement smaller style games within their own; these examples include Mario Party (*Mario Party™ Superstars*, 2020), WarioWare (*WarioWare: Get It Together!*, 2020) and Rocksmith (Graham and Schofield, 2018). Particular attention was paid to Rocksmith as it was one the core concepts that this research attempted to replicate, albeit using the keyboard as the main controller rather than

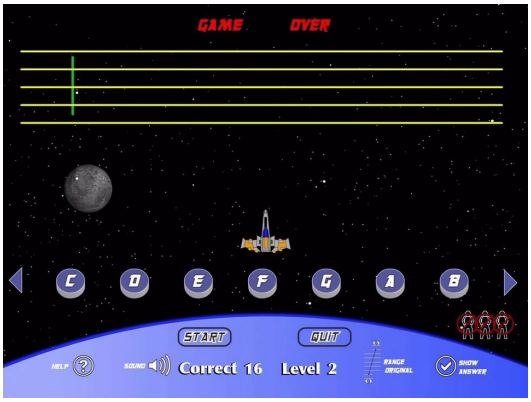
a guitar. Rocksmith had featured a ‘Guitarcade’ which was a series of arcade style games that helped build particular skills when playing the guitar – practising scales in a racing style game or playing chords to shoot zombies.



(a) Rocksmith’s ‘Guitarcade’ mini-games



(b) Audiation game featured in the online collection of practice games developed by Theta, a take on Breakout



(c) ‘Staff Wars’, a simple note reading practice game which has a ‘Star Wars’ theme and a timer for added agency

Fig. 4.1 Various inspirations which were reviewed when developing out mini-games

Other inspirations included typing games, most notable was *ZType*, where one must type words to destroy oncoming waves of enemy ships, and later expanding this idea to be horizontal to reflect real world applications of reading a musical staff. Finally, inspirations were based on mobile games, particularly *Stack* and *Crossy Road* but replacing the core mechanic of simply touching or hitting a key, with playing specific keys. Whilst more games

were reviewed and consulted at this stage, they were mostly used for discussion points or to borrow specific designs – a full list of games is made available in the appendix.

4.2.2 Development Process

It is the belief of this research that when developing new solutions for an issue which allows for such a large array of ideas, rapid prototyping is key and this was also backed up by the supporting literature. It allows one to not get distracted by over graphical solutions in which too much time is focused on aesthetics rather than function and meaning. Developing in such a quick fashion, especially ideas which require some complex principles such as rhythm and syncing MIDI interfaces, can be seen as a somewhat tricky undertaking. Fortunately, with the advent of game engines, this process is less overwhelming. The Unity Engine (Technologies, 2005) was used to develop of prototypes as it is lightweight and offers packages which assisted in the development (it helps shortcut game development pressures such as physics and collision modelling, creating UI functionality and allows projects to be built to mostly any platform with ease). Below is an outline of the development pipeline that was adhered to, walking through the step-by-step process of initial concept to prototype.

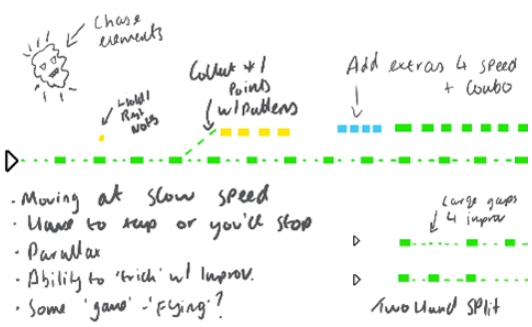
Development Pipeline

A typical pipeline of development was followed which included internal and external testing (using Fullerton's model (Denham, 2016)). This process was useful and it could be used iteratively by looping the entire process – from brainstorming an initial idea to external testing (i.e., testing on the public) this could be repeated on what was discovered through testing until a solution that was satisfactory of the aims that had been set out to achieve was found. Each step is listed below:

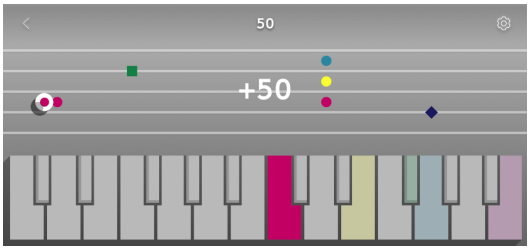
1. Brainstorming Ideas

Each concept began with creating new ideas for possible products that could be added to the ever-expanding portfolio. This typically began with group sessions which focused on a single idea, for example 'A game which helps beginners learn the basics of rhythm' or 'A game which centres around a beginner learning to read basic musical notation'. Ideas would be discussed and eventually a list of the favourite ideas was created (typically by voting); concepts would be hand drawn concepts later draw out more complex designs digitally of the most favourable concepts. A key lesson learnt was to not just consult gamer archetypes or developers but expand the discussion circles to anyone who had an idea – some of the best ideas came from those who were not too involved with the development process and allowed creativity to flow.

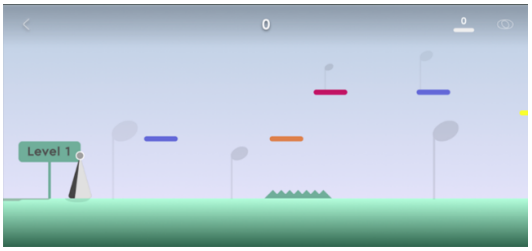
(a) Hand Drawn Design of an RPG Game



(b) Hand Drawn Design of an Infinite Runner Game



(c) Concept Design of a Staff Shooting Game



(d) Concept Design of a Platformer Game

Fig. 4.2 Concept Designs For Various Learning Mini Games

2. Internal Prototyping

Once an idea had been decided upon, occasionally deciding on the top three ideas, prototyping would begin. As mentioned, the Unity Engine was used to allow for rapid prototyping and built a set of classes and namespaces, using C#, which could be called upon, rather than having to create similar functionalities every time a new prototype was to be developed. There were functions which were required across protypes, such as adding and tracking score, linking MIDI actions to specific mechanics using event triggers and more complex functionality such as generating scales. Inheritance was used to implement these functions within smaller classes and individual games. For example, one script would handle adding score which would execute other actions such as updating UI and a child script could make use of this by calling upon the adding score function when the player completes a correct action within a specific game – ensuring that developers would not have to write a scoring script for every single game.

Finally, the development team made use of source control, using *Git* and *GitHub* to store the repositories. The source code for all of games was available across the company to allow anyone to add their own mechanics and implement their own code, using their own branches. All games were contained within one project which could later be built within the LUMI application, ensuring that it would work with the application and match the design

of the entire ecosystem. Source control was also used by the individual researcher - it is a practice which should always be followed, as it allows for retrospective glances of older work, prototyping smaller sections of games without affecting the entire project and works as a way to back up work. Whilst the repositories cannot be made publicly available (as it breaks IP laws), code snippets are made available on GitHub which gives developers access to the aforementioned parent classes and namespaces – if anything they are useful to study to understand the principles of SOLID coding (Kexugit, 2014) and act as a foundational pieces for developing music games, especially educational ones.

3. Internal Deployment, Validation and Testing

Once a prototype was developed, it would be deployed to the local builds which the entire team could access. TestFlight was used for distribution as well as using the App Centre as the ROLI build architecture was mostly Apple dependent. All team members played the games and gave feedback, rather than just being played by the designers and developers. This helped to notice any major bugs and points of frustration whilst also regularly meeting to discuss how to improve upon the experience based on the feedback given. It was important to test on non-developers and designers to ensure that it could be played without much assistance before the games were showed to the wider public audiences. It was clear when a prototype was highly engaging and received positively by the excitement across the company; seeing large gatherings around a team member playing the game or being requested to play regularly.

4. Production Development

Once a handful of games were tested internally, it was somewhat obvious which prototypes were the most well received (a lot of this boiled down to observing players for the first time whilst asking open-ended questions; the initial response spoke a thousand words). These prototypes were taken further and were developed to a production level that would be appropriate enough to show to the public. This entailed fixing the bugs and points of frustration, adding more detailed design rather than simple white boxing (Zammitto, 2018) and ensuring that the overall UX flowed well enough that the researcher would not have to interfere with the users too much at runtime.

5. External Testing

The final step of the pipeline is external testing. At first, the play testers were either friends or family of team members, rather than showcasing to unknown members of the public. This was to avoid showing something which may have been reviewed negatively and then be

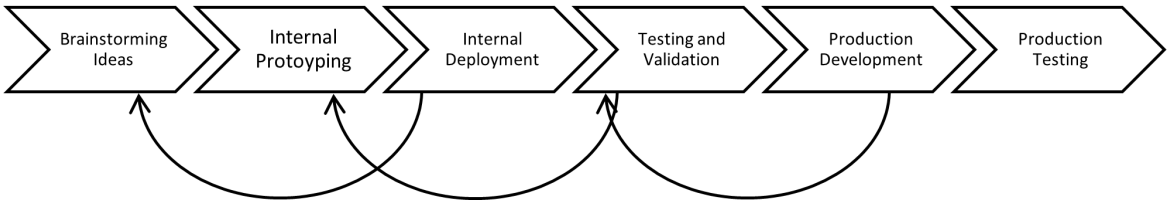


Fig. 4.3 Overview of the Development Pipeline; iteratively cycling between internal discussions and brainstorming until an idea was formed before cycling through development and testing until a feasible prototype was developed that was appropriate for public review

spread around to a wider audience and because it was opportunity to test on those who had no idea of what the internal goals were without the need to actually recruit.

If an idea seemed to catch the attention of a wider audience, these ideas would be taken further by testing on the public and the first study of this research, which is outlined below, is the first iteration of this testing. Once the games had been tested, feedback was taken onboard and the team went back to the brainstorming stage to discuss potential extensions of each game or whether the idea should be halted and look to another direction.

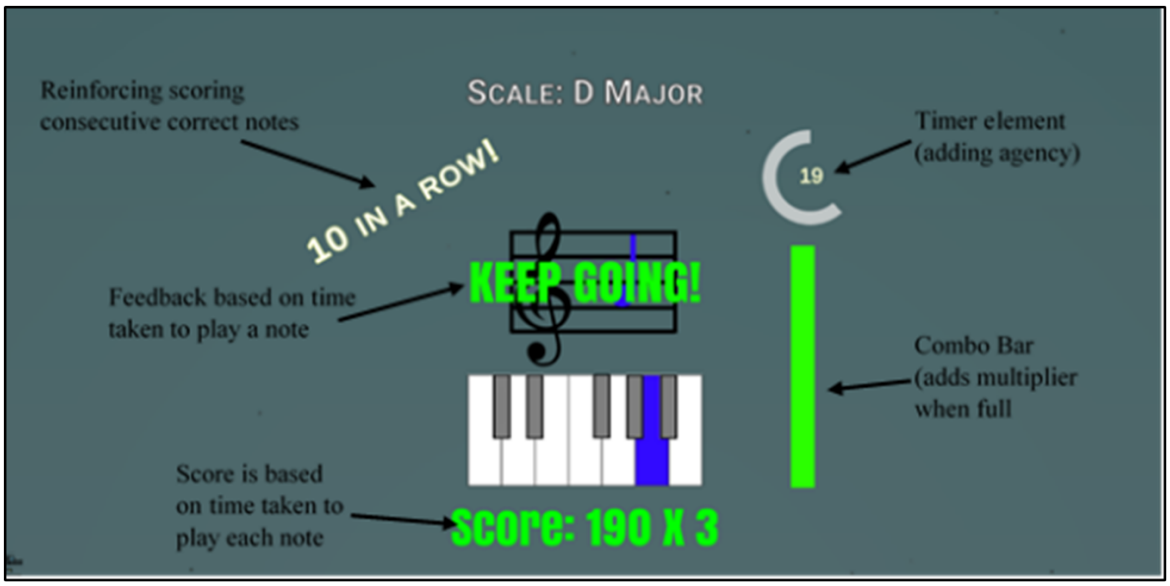
4.2.3 The Mini Games in Detail

Using the above methodology, four prototype games were developed which made up the suite of mini games. Each game is described below before discussing the intended learning objectives, and the potential extensions of each prototype.

Note Flash

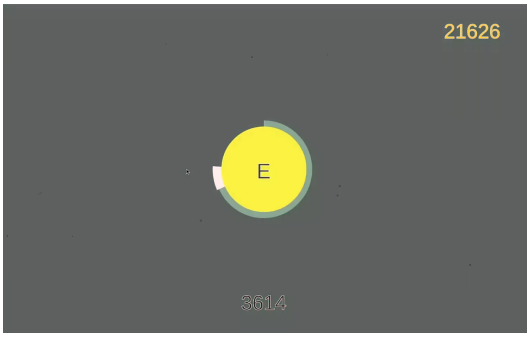
This is a game in which a visual cue flashes on the screen (either a note shown as a letter or in notation) and players must play the corresponding key. The loop of the game is to get the highest score possible within a set time limit; the faster you press the corresponding key after it is shown, the higher score you are rewarded with. If users get five notes in a row correct then a multiplier is applied to the score.

Players are encouraged using mostly positive feedback loops, i.e. playing a correct note is signified by a positive and encouraging bell sound which increases in pitch with each consistent note played. Whilst this is positive (rewarding for good behaviour), the idea of building up a number of consistent notes in a row means that the more consecutive notes a player scores, the more investment they have made and will want to avoid playing an incorrect – this is what is called a sunk prison cost, based on Chou's definition within his gamification research (Chou, 2019).



(a) Annotated screenshot of Note Flash version 1

(b) New Design of Note Flash using notation



(c) New Design of Note Flash using letters

(d) Note Flash implemented into the LUMI application

Fig. 4.4 Mini Game One: Note Flash

Intended Learning Objectives

The main aim of the game is to help beginners build association between notes on a staff or letter representations of notes and physical keys on the keyboard as well as familiarise themselves with the pitch of each note. The objectives can be extended, such as learning scales by showing notes in a specific pattern, basic rhythms and reading more complex notation. It is intended to be played by beginners initially but extending the purposes of this game also broadens the scope of what type of learner it can cater to; notations of chords, rhythmic notation and playing in specific keys.

Extensions of the Game

- To avoid pressure felt from the timer element, a 'level mode' was created; in this version, players must fill a bar up by playing corresponding notes. Once the bar is completely full, the game is won. Just like in the original version, the quicker a note is played, the more the bar will fill. The idea that players' actions contributes towards a win state should hopefully give a sense of satisfaction and accomplishment (rather than always having to beat their previous score to 'win')
- To help reduce frustration of the players that have to constantly look at both the screen and the keyboard, a variation was developed in which a visual cue (a note, chord etc.) appears on screen for a brief moment before disappearing; after it disappears, players are given a set amount of time to play the note. If they do not play the note in time then they will lose a life and eventually lose the game. To complete a level, players must successfully play a total of notes

Note Typer

The core loop of Note Typer is to prevent 'enemies' falling below the screen. Phrases (enemies) fall from the top of the screen. If they fall beneath the screen then the player loses a life (with three lives available in total). To destroy an enemy, players must play out each phrase (the order does not matter, i.e. they could play the last phrase to appear before playing the one closest to the bottom, and this actually results in a higher score, a 'close call' score is added depending on how close the enemy is to the bottom of the screen – playing on the 'Evanescent Opportunities' driver of gamification (Chou, 2019)). The enemy phrases appear in waves and increase in quantity of enemies and the speed of the enemy with every other wave; this regular up and down motion of difficult is referred to as 'a series of ascending arc' (Holleman, 2019) and ensures the game has moments of rest rather than

continuously ramping in difficulty. Each ‘phrase’ is designed to help improve fingering skills at the keyboard; using ‘thumb under’ techniques, improving ‘five finger position’ and so on.

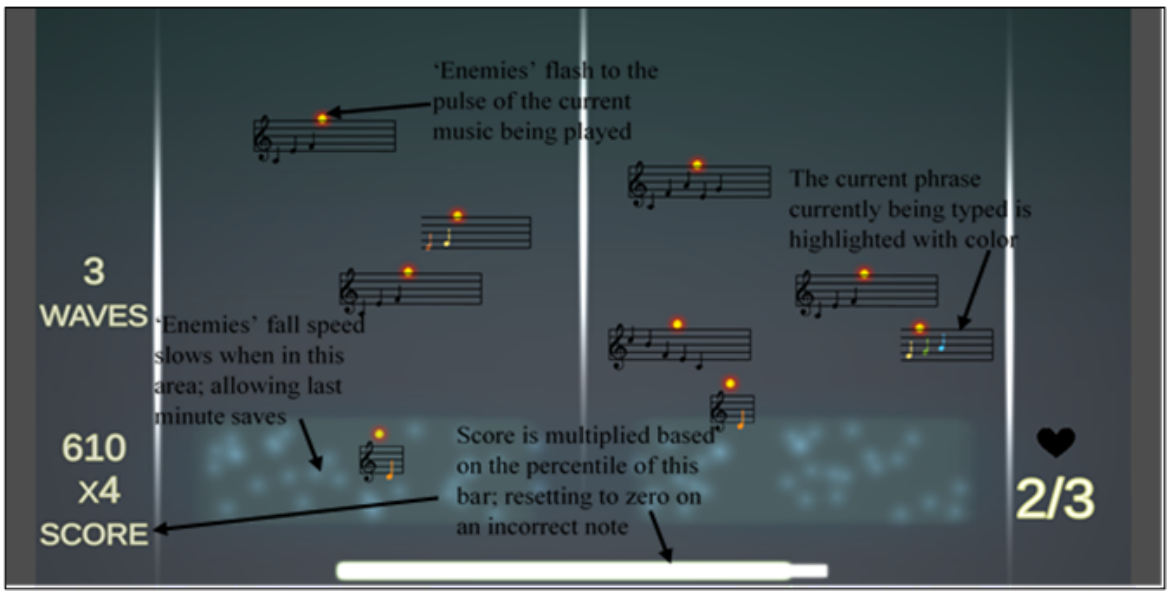
Player actions are reinforced with positive feedback loops; playing a note in each phrase omits a friendly chirp sound in the pitch of that note (reinforcing audiation) and destroying an enemy results in the phrase ‘exploding’ into smaller pieces (increasing the amount of ‘juice’ (Hicks et al., 2019) adds to satisfaction and overall engagement. In addition to this, there is also a ‘power bar’, which fills up on each consecutive note played in a row and requires five consecutive correct notes to be filled. Upon being filled a multiplier of the player’s score is applied and this also unlocks a ‘weapon’ which destroys all enemies within a certain range. Rhythm has also been implemented; using the algorithm from previous prototypes players are rewarded extra points for playing with the tempo but this is not strictly necessary to destroy enemies; this tempo is denoted by the flashing of ‘enemies’.

Intended Learning Objectives

The learning objectives are similar to Note Flash, but focus more on hand coordination and rhythmic skills. As with Note Flash, the learning objectives are extended, helping learners to play with two hands both together and independently whilst also sequencing notes in patterns which help specific finger techniques (for example, reiterating the fiver finger position).

Extensions of the Game

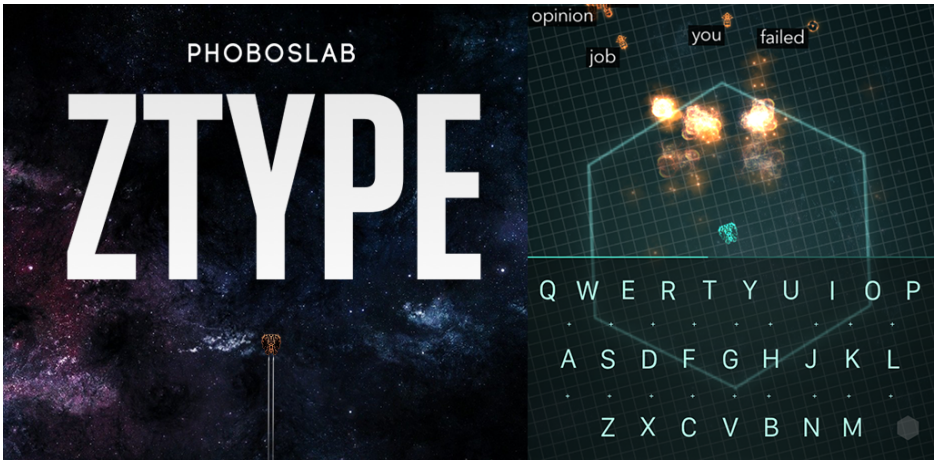
Initially, the game was designed with enemies falling at random positions across the entirety of the screen. The concept of ‘two-hands mode’ was introduced as an extension for those that wanted to practice similar concepts but with two hands. A split down the middle of the screen was made: notes that fell on the left side were to be played with the left hand and vice versa. Later, chords were introduced; either side could produce chords (although typically it was the left hand to reflect real-world applications) and players must play chords seen on the left whilst also having to play phrases on the right. This led to the idea of having the chords and phrases generated in a way that would create something similar to an actual song which should help to increase general competency with music and engagement. To make the game feel less monotonous a ‘quick tap’ mechanic was added; during each session a series of notes or just one note will spawn in quick succession and the player must tap the corresponding key as quickly as they can. The idea behind this was to help break up the session and add an extra layer to the game. This is in line with the use of unpredictability found within gamification theories (Chou, 2019).



(a) Annotated Screenshot of Note Typer

(b) Older version of Note Typer using letters and exploding notes

(c) Older version of Note Typer using letter phrases to improve finger techniques



(d) 'ZType' the game which helped inspire Note Typer

Fig. 4.5 Mini Game Two: Note Typer

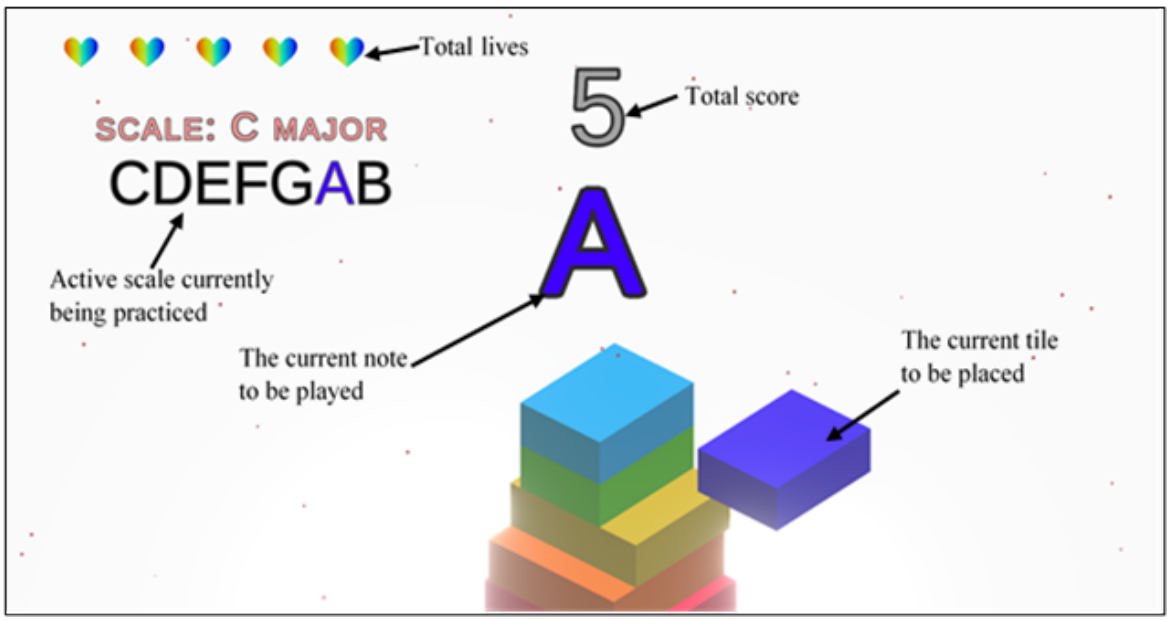
Note Stack

Based around the ideas derived from a similar mobile game, *Stack* by Ketchapp Games. The core loop in this game revolves around playing corresponding notes shown on screen or playing through a scale in order to place moving tiles on top of one another to create a 'tower'; the higher the tower, the higher the score. The core loop is simplistic but it is because of this that players want to return; players feel as though they could score higher next time and because it is easy enough to try again, they will. If the user plays at the right time (either by using rhythm, using a metronome, or by visuals) then the tile will match perfectly on top of the previous one, if three perfect tiles in a row are placed then the size of the next tile increases slightly in size; making it easier to place, which can lead to higher scores or can help a player who has fallen behind. As with all the prototypes, notes can either be coloured to reflect the colours of the keyboard or in black and white (to reflect a more traditional approach).

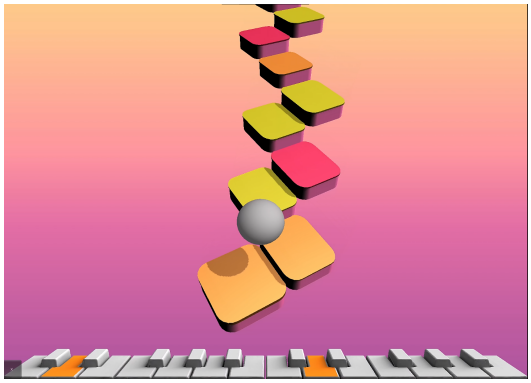
Feedback is offered in two forms; visually, the player will see a glow if they place a perfect tile or, if they do not place it perfectly, whatever part of the placed tile that missed the previous one will then be cut off, resulting in the next tile placement being a smaller target. The second form of feedback is auditory; a perfect placement results in a satisfying bell sound which increases in pitch on each consecutive perfect placement, whereas a non-perfect placement results in a snapping sound and resets the pitch back to default. Finally, playing an incorrect note does not place the tile but removes a life (with three lives available in total) and if all lives are lost then it is game over.

Intended Learning Objectives

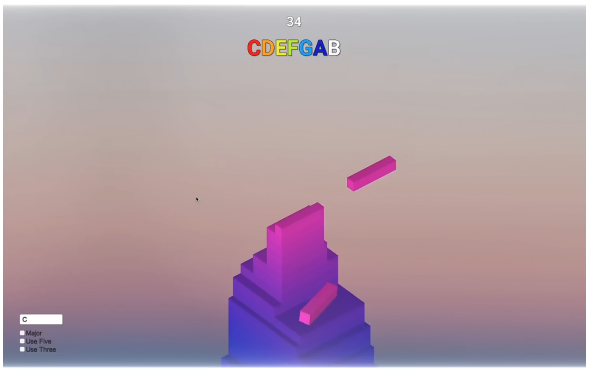
Due to the nature of the core mechanic and the use of existing game design paradigms, the learning objective was relatively simple but there is room for extending this. At a basic level, the game helps players to learn scales, improves their overall sense of rhythm and helps to learn specific finger techniques whilst improving overall hand dexterity. Additionally, players who are beginning their learning journey could use it to learn simple concepts such as the familiarity of notation, if this view mode is selected, rather than showing note letters.



(a) Annotated Screenshot of Note Stack



(b) 'Note Tower', a version of Note Stack implemented into the LUMI application



(c) Note Stack being played, the colour of the tower reflects the colours of the scale practiced

Fig. 4.6 Mini Game Three: Note Stack

Crossy Notes

This prototype is based on an existing game, *Frogger* or, the modern take on this, *Crossy Road*. The objective is to cross endless roads and avoid obstacles as far as possible without being hit. The game consists of endless obstacles such as rivers, cars and props. and players must time their movements to cross each lane without being hit by a car. The camera constantly moves forward and if the player takes too long to move and fall outside of the camera's view frustum then this will result in game over. Feedback is offered by rewarding the player with score on each successful forward direction and additional points can be acquired by playing chords scattered throughout the game. In this version, players must move forward by playing

an ascending scale (the option to move backwards is also offered by playing the previous note in the scale).

This was the first game to make use of more than two octaves, by joining two LUMI keyboards together (which the hardware allows). The size of the keyboard increases to forty-eight keys; keys on the lower side are used to play chords and move left/right whilst higher notes are used to play through the scale and move the player forward. Playing an incorrect note results in the screen flashing red and an off-putting sound being produced; no score is affected as this was deemed too punishing for beginners.

Intended Learning Objectives

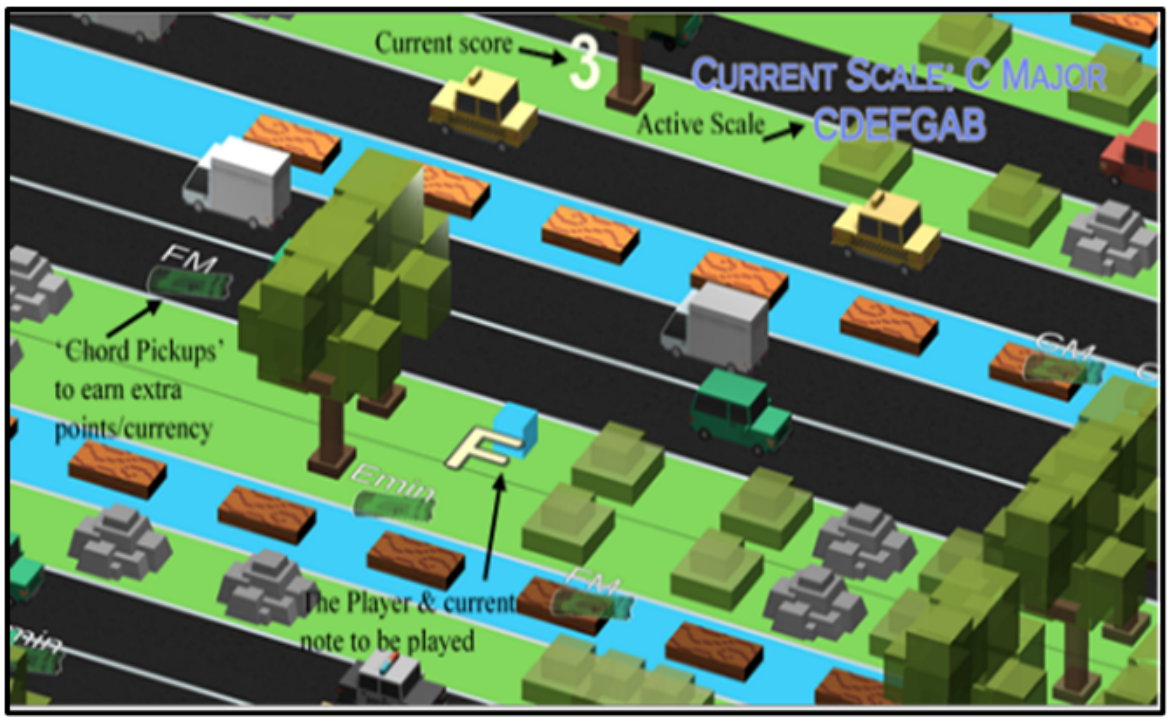
This prototype is not a typical learning game and as such its dedicated learning objectives are up for somewhat of a debate. The core of the game revolves around playing repeating scales which change over time (i.e. players input which scales they want to learn and these change over time). However, the nature of the mechanics and the idea of the game lend themselves to a broader range of learning objectives which have yet to be defined. One core concept is rhythm, which was later implemented; if players move forward in time to a certain tempo then they should be able to cross the road without being hit. The game helps practice rote areas of instrument learning; playing through scales as well as helping learners familiarize themselves with two hands at the keyboard.

Extensions of the Game

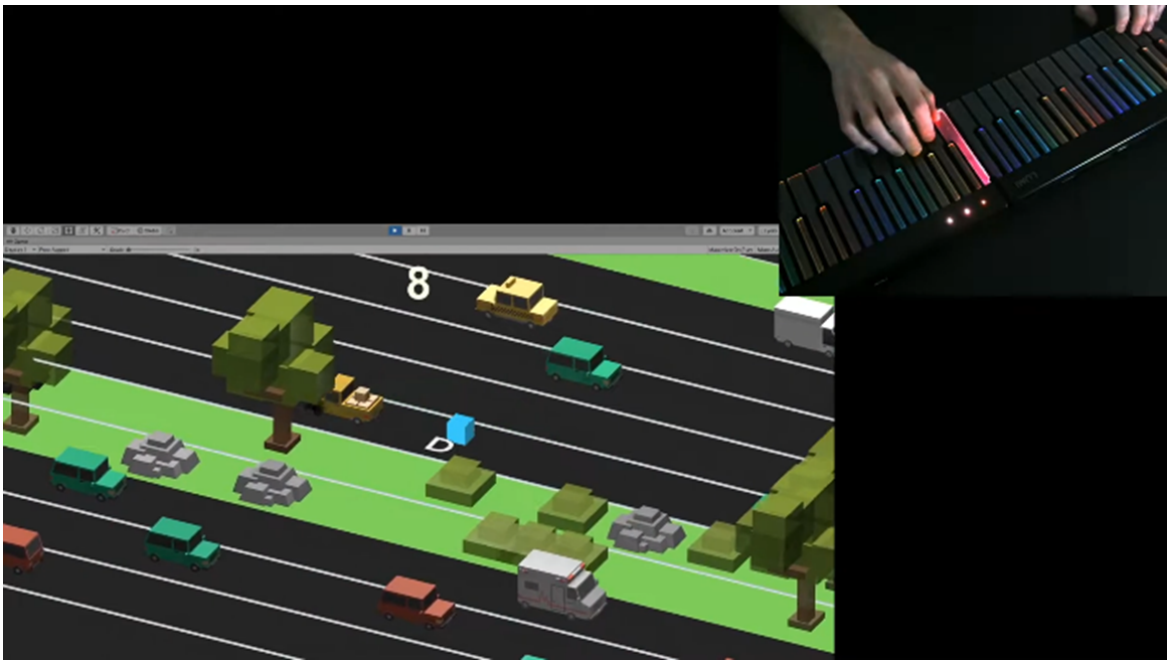
The game increases in difficulty the further the player travels. Difficulty is measured by a few facets; the scale itself (the mode of scale or starting from a sharp/flat key), the rate at which cars spawn and the average speed of cars. This means that eventually the player will loose and the incentive to play again is based around a need to beat their previous score or their personal best. Future directions that were considered include implementing ‘levels’ in which players must reach a goal rather than seeing how far they can go and this should help provide the player a greater feeling of accomplishment (completing a level consistently as opposed to constantly trying to beat their high score). Finally, additional learning objectives were required to be set and defined through user testing and development.

4.3 Testing the Mini Games

The first step in assessing the suite of mini games was running an initial small-scale study. The study would allow participants to speak freely about their prior learning experiences to

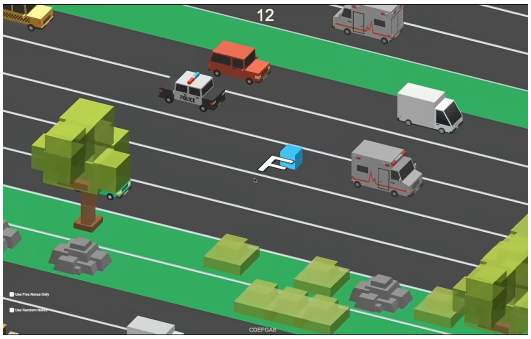


(a) Annotated Screenshot of Crossy Notes



(b) Crossy Notes Being Played with the LUMI

(c) 'Crossy Road' The Inspiration for this game



(d) Crossy Notes played during a study

Fig. 4.7 Mini Game Four: Crossy Notes

get a deeper understanding of the research's key issues. The sample was mostly reflective of the research's target population but was also extended to intermediate and advanced users as it was of concern of what current beginners were frustrated by but the common themes that other learners had faced in their early stages of learning. This is the first lesson other developers and researchers to consider: ensuring that their process is an iterative cycle of development and testing, with a key focus on testing more than actual development (as is apparent in the mini games - they were not overly developed which avoided wasting time developing assets which would eventually be forgotten about).

The study's goals was multi-faceted and the nature of the interviews was semi-structured as the research was still pin pointing specific areas of frustration and where video games would be most beneficial. The goal to improve the user experience and determine how educational a specific gamified experience can be. Specifically, the key questions of the study were:

- Why do beginner learners drop off/give up? Reasons for this had been established using secondary data and personal insights, but it was the decided that this would be explored and confirmed through the use of primary data
- Are the games developed focusing on the right areas and which game was the most ideal solution for the key issues, i.e., do they have the right scope?
- Were the games deemed enjoyable, within consideration to usability, time spent playing, difficulty, observed engagement, design and educational value?
- Regarding enjoyment, educational value and motivation, how can one measure these criteria empirically and furthermore, what lessons can be taken from the initial study to improve future ones?

4.3.1 Participants

Participants were recruited (N = 10) using opportunity sampling through mailing lists and also ones familiar to the researchers. Participants were mostly beginner musicians (or at least beginners in reading music), over the age of 18, a mix range of genders and, for the most part, had at least some experience playing video games.

Table 4.1 Study One Participant Demographics

	Age Group		
Demographic Information	18-24	25-34	35-44
N (Count)	1	5	4
Gender (count)	1M(100%)	3M(60%)	4M(100%)
Use Applications To Learn Keyboard (count)	1Y(100%)	3Y(60%)	2Y(50%)
Video Game Player (count)	2Y(50%)	3Y(60%)	2Y(50%)

4.3.2 Procedure

Before commencing with the play session, introductory questions were; this was to give insight into the background of the participant, where the overall information has been disclosed prior.

The second stage of the study was the play session in which each participant played each game (discussed prior) for a total of five minutes. The games were broken into two categories: gamified practice tools and training games. Whilst similar in nature, the two groups featured two mini games (the gamified practice tools contained Note Flash and Note Typer, whilst the training games featured Note Stack and Crossy Notes); this split of the games would help to demonstrate where the line of gamified practice and video game would naturally occur. The researcher observed the participant in real time and observed their play via live streams of the desktop from a remote machine. Each game was played with the LUMI and participants played each game from the least game-like experiences (i.e. those that more closely resemble brain training applications) to those that are akin to a casual mobile game in order to gauge how much a learning experience can become a gaming experience.

Related questions were asked in line with the study aims after each game had been played and a final set of questions was asked once all tasks had been carried out; any remaining comments were encouraged to be given by each participant in order to ensure that all opinions had been gathered.

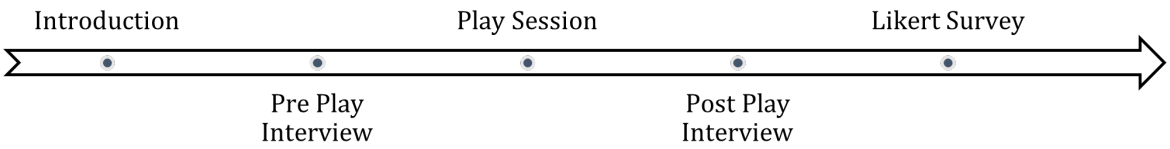


Fig. 4.8 Timeline of the Study Procedure

A full list of every question and the entire study protocol is available for review in the appendix.

Hardware Considerations and Setup

As the games developed were to be integrated into or alongside the LUMI learning application, the main hardware for this project, and the controller of each game, was the LUMI and as a consequence, games developed fit within the colour schemes of the keyboard – using aforementioned theories of cognitivism (Zinn et al., 2015) to reinforce learning through the use of colour.

The LUMI was placed in front of a MacBook Pro, along with an external webcam which recorded the participants hands during the session – this was to see how they used their hands and what impact playing a game would have on form (whether or not these games could be useful for improving executive functioning skills (West, 2015). Although participants were observed first hand, the MacBooks camera was used to record the participants reactions to each game, whether or not they were observed as confused, frustrated, happy etc. The screen was recorded during their play sessions to observe points of confusion and frustration as well as areas of high engagement – these recordings were made available to the whole research team and were consulted during data analysis. Finally, the interviews were recorded using the microphone attached to the external webcam, later transcribing the interview data for analysis.

4.3.3 Ethical Approval and Covid-19

Ethical approval was received in line with the University's policy as well as any precautions relating to Covid-19 . Multiple precautions were taken for safety, adhering to the Government's policies and regulations. Participants were introduced to the researchers from a distance outside the premises before ensuring they were wearing a mask upon entry. Upon entry, all participants and researchers sanitised their hands and whilst conducting the study remained at least a foot apart in distance. Participants sat down at the desk where the study would commence and were required to handle the laptop interactions (i.e., opening each gamified solution) as to avoid any close contact with researchers and to avoid cross contamination of touch points. Finally, after each participant was finalised, the testing station was thoroughly sanitised before allowing the next participant to commence.

4.4 Results

Data was collected through multiple methods: recordings of both the participant and the recorded gameplay, observations conducted in real time and answers provided by each participant were written down in shorthand form and recorded during the interview process.

As previously mentioned, the participants were varied in musical skill, from those who had musical degrees to casual musicians; only one participant had never participated in learning an instrument. The analytical approach needed to be flexible to respond to the differences within the data collection methods utilised, thematic analysis (Nowell et al., 2017) provided this flexibility and was deemed the most appropriate method.

4.4.1 Music Education Insights

One of the first questions posed to participants revolved around their methods of learning, specifically asking, 'How would you go about learning to play keyboard/piano?'. This was a useful question as it helped determine where exactly the prototype practice games would fit into an existing learners journey. Over half of the participants had used a teacher with a series of books (the most traditional and popular method for serious learners). Others had learned from their friends and families who were musicians whilst, surprisingly, only 2 participants had used learning applications, and their experience with them was quite limited. This helped to determine that most serious learners already have a method of learning the fundamentals and define their own unique learning journeys; what they required the most was a method of practicing skills which were applicable to the application of their learning and would help expediate the learning, rather than a method which tries to replace their whole journey.

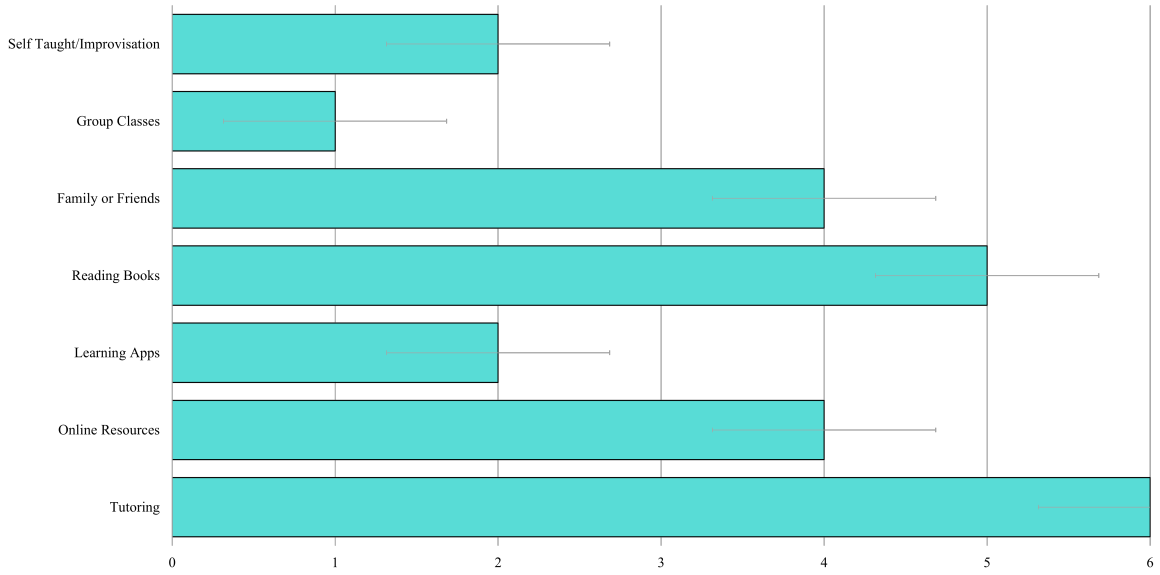


Fig. 4.9 Bar Graph Outlining Methods of Learning for All Users

Overall, it was found that most participants had at least some exposure to music education during the early stages of their lives, typically being made to attend lessons by their parental

figures or were involved with music as their family backgrounds were musical. Those that had less experience or no experience at all, did not have this level of exposure or experience to music. Whilst they were avid music listeners, they had no connection to playing or understanding, highlighting that for adults to have this type of exposure would require rote learning or at least a substantial amount of time committed to playing and practicing. The absolute beginners and lapsers consistently mentioned the lack of inspiration they had to practice on a regular basis and the frustration of trying to accomplish a task but struggling due to the lack of skills. It was clear that casual learners wanted to express themselves but never could and when seeking new methods of learning they were still hit with a wall which required consistent and tedious practice to climb.

It was established that the reason most of the participants eventually dropped out of learning music at some point was that they found no personal connection to it (the fact they were forced led them to associate negative feelings with playing). Tedious practices also led to negative connotations around playing and, finally, most of the participants wanted enjoyment out of playing; they never really saw the application of what they learnt and found typical ways of practising a bit bland and meaningless. The participants who had experience teaching, also claimed that it was difficult to get their students to practice on a regular basis and show up to lessons consistently. Whilst they thought the use of gamified learning applications could be useful, they worried that this method of teaching would lead to poor technique without the use of an experienced player to critique them. However, what the teachers could benefit from is a gamified method of practicing specific skills which could also grade their participants accurately regarding that specific skill. They claimed that there were specific areas of learning which would always be deemed as tedious such as finger exercises, practising reading or writing musical notation and learning patterns such as chord progressions and scales. They would prefer a suite of practice tools to work alongside their teaching rather than a replacement for the entire teaching philosophy.

4.4.2 Feedback on Games

To provide insight into how participants perceived each game, and how this can be improved upon, participants' responses to each game were analysed. Each participant was observed whilst playing the game, specifically looking at whether they were using the correct technique, were encountering frustration in specific areas, how engaged they were and how easy the system was to use. In addition to this, specific questions were asked relating to the Scope of Game, Design, Usability and Enjoyment/Engagement; this set of criteria was defined specifically for this research in line with the main aim of the project. This procedure was followed for each game before asking questions relating to the whole experience. Through

analysis specific sub-themes were defined relating to the primary themes; whilst most sub-themes were shared throughout each game, specific critiques were also found for each prototype game. Below is a list of each of these themes and sub-themes. This is then followed by an in-depth analysis of the data regarding each theme, for each game. Finally, a general overview of the games is provided.

Scope of Games

Three sub-themes emerged when reading through the transcripts in regard to the scope of the games (referring to the application regarding a specific educational objective). The application itself, improvements that can be made to ensure that it teaches the right content, and how the game could/would be used in conjunction with the participant's typical learning. Responses provided regarding the games' educational value and how well this was rated (using a Likert scale approach of 1-5 in terms of rating, with 1 being the least educational) were analysed.

Design

Three sub-themes emerged when analysing the data regarding design (the aesthetic elements). These themes were SFX and VFX, how the game 'felt' (regarding overall themes, mechanics etc.) and, finally, music related (this is different from sound effects and pertains only to how music was used in each game). It is important to note that the games were in early stages of development, so efforts made relating to design were mostly focused on the use of colours, specific sounds etc., rather than the quality of the design.

Usability

Usability refers to the overall user experience of the application and how easy or difficult it is for a user to understand the concept of the game, navigate menus and whether the game is too hard or too easy. Two sub-themes became apparent when analysing the data: difficulty and complexity (was the game too hard/too easy, was the concept too complex to understand etc.) and frustrations (what gave the participants frustration relating to how the game is played and/or the user experience is handled).

Enjoyment/Engagement

It was important to understand two concepts regarding the enjoyment of each game: was the game actually fun and are there trends in both what was observed and within the answers

in order to provide criteria to improve upon. The second concept was interactivity (or engagement), referring to how interactive each game was, and this was mostly derived from observation; was the participant too distracted to answer questions and, did they want to continue playing outside of the time limit? Through the use of Likert scales (1-5) participants also rated how much fun they had (with a rating of 1 being the least fun) and how likely it is they would want to play again, given the opportunity.

Note Flash

Below is an analysis of the first prototype game, Note Flash in which the results are discussed based on the pre-defined categories of scope, design, usability and engagement.

Scope of Game

All participants agreed that the idea of the game would be useful at the beginner stages as well as later stages. For example, the more experienced participants commented that the 'Chords etc. are good as it adds difficulty'. Observing the participants play also showed that they were using the right fingers to play each note and gradually stopped looking at the keys, showing confidence at the instrument. One participant stated, '[the game] forces you to learn note positions without looking at the keys'. What participants wanted was more challenge and this was typically in the form of rhythm or audiation skills. Participants wanted clearer sounds when playing the keys to determine the sound quality of it. It was apparent that participants were worried they would be reliant on colour and the application to something more organic, such as playing a song, could be missing.

Design

Participants had specific comments regarding design and mechanics. Most commented on the 'floating dust' (the particle effects) being a good thing, '. . . floating dust is also nice as it adds atmosphere', but a few participants stated that it distracted from the game and wanted to focus on the mechanic rather than how it looked. Regarding sound effects, almost all participants commented on the sounds played when answering a correct question (it was a satisfying bell sound) but they wanted to hear the actual note (a sound that actually reflected the actual note). Participants also commented on the sound and effects when playing an incorrect note, saying it was too abrupt and caused discomfort, 'the wrong sound is too harsh'. Finally, most participants wanted to know what the correct answer was if they got it wrong, otherwise they felt they would not improve/progress.

Usability

Most participants agreed that the game was the right difficulty and enjoyed that it started easier and gradually got more difficult. A few participants stated that the game was too quick to begin with, '... the timer is too tough on the first go and should start slower'. The concept of the timer and the core mechanic were easy to understand but, it could be argued, perhaps a little mundane., Adding additional layers of music such as rhythm should help address this issue. Most participants agreed that it was an easy concept to understand but navigating menus and actually starting the game was slightly confusing; 'UI needs improvement'. Although the idea of agency is a common theme within games, a couple of participants mentioned that the sense of agency when attempting to learn something new can be frustrating and lead to feelings of anxiousness. Finally, the idea of allowing participants to choose their learning objective might not be ideal; participants seemed to want a clear path of progress to follow.

Enjoyment/Engagement

One participant noted that the game has 'An addictive attitude', in which they would want to come back and play again because of how easy it was to jump into and felt as though it had challenged their knowledge. What was deemed enjoyable about the experience was the challenge itself. When more experienced participants found the Chord Mode setting, they immediately became more interested and when they gave incorrect answers this did not deter them but in fact encouraged them to try again to beat their previous score and ensure they get the right answers next time.

Note Typer

Below is an analysis of the second prototype game, Note Typer in which the results are discussed based on the pre-defined categories of scope, design, usability and engagement.

Scope of Game

All participants agreed that this game had substantial application and could be used for further complex techniques. They agreed that the game would be great for practicing rhythm and fingering exercises; 'A good learning tool; lots of application'. However, what participants requested was that they wished there was more structure and to sound as though they were actually playing a melody or being forced to play in time more, 'Everything moves at different rates unlike sheet music that doesn't move.' When experienced musicians were introduced to

the ‘phrase mode’ they found this much more challenging and agreed that it could be useful for practicing basic rhythm control, correct fingering and reinforcing sight-reading. When participants played the ‘two hand mode’ they all struggled to look at both sides of the screen, opting to clear one side before clearing the other, indicating that this game is not an ideal candidate for practicing two hand technique. Participants could see this game being used as exercises to be employed in conjunction with their own learning methods, ‘Good to start with/warm up exercises’.

Design

Most participants enjoyed the design of the game, commenting, ‘Very much like other arcade games’ and ‘retro’. They all found the error noise a bit ‘jarring’ and almost all participants said that the notes ‘exploding’ was ‘satisfying’ but also detrimental to playing well, ‘Explosions cover the notes too much’, requesting that they are smaller or slightly more transparent. Most enjoyed the ‘panic’ when playing and trying to ensure that the notes do not fall below the screen; the idea of building up levels and consecutive right answers led to participants being more cautious and getting less incorrect answers. The most important aspect of this to note was the ‘disconnection between sound of notes and the soundtrack’. Participants wanted to feel as though they were playing along with the soundtrack and the idea of playing notes as quick as possible resulted in the sound being ‘clunky’. Finally, because this game was infinite (i.e. play until you fail) participants began to get tired of the backing track, ‘I got sick of the same tune over and over again’.

Usability

Whilst the concept was easy enough to grasp, participants stated that they wanted a bit more of a challenge. The concept of notes falling was familiar with most participants, ‘Used to falling of notes; akin to YouTube vids etc.’, which made the game easy to approach. Frustrations stemmed from the fact that notes would be covered up by the visuals (the explosions) and this hindered how well participants could play and occasionally resulted in unfair game overs. Whilst the navigation of the game was deemed straightforward, as participants could see in real time what the different options meant (i.e., visual representation of options), they felt as though some explanation or acclimatisation was required.

Enjoyment/Engagement

All participants clearly showed states of ‘flow’ when observed and would struggle to comment when playing, being too distracted to do so. Participants claimed that the single note mode

was somewhat dull but found joy in getting multiple notes in a row correct and found playing out phrases the most satisfying and enjoying. The idea of notes 'exploding' when getting the right answer made participants more engaged with the game, '[Note Typer] is much more interactive!' one participant commented when discussing this (in comparison to typical practice).

Note Stack

Below is an analysis of the third prototype game, Note Stack in which the results are discussed based on the pre-defined categories of scope, design, usability and engagement.

Scope of Game

Participants were split on the purposes of this game, some felt as though it could be a great way to practice scales, 'Great way to learn scales as it is all laid out!', whilst others did not associate this with the practice of scales and felt it was more about muscle memory. A number of participants (mostly those that had some experience) claimed that the practicing of scales typically includes playing up and down the scale whereas, in this game, one only plays up the scale (indefinitely). All participants commented on the fact that the audio did not match the visuals and when trying to place 'perfect tiles' on the beat (on the click of the metronome) they struggled as it was not quite right. Participants also felt as though showing the actual scale on the keyboard (i.e. highlighting the keys that belong to the scale) and showing the scale on an on-screen keyboard with correct finger placements would be more beneficial than just seeing it spelled out on screen.

Design

The main concern from the playthrough, from both observation and remarks from interviews, was that the visual of the shifting tiles did not match the actual rhythm of the metronome or backing track. This led to participants placing tiles incorrectly and having to account for this delay between sound and visual. Besides this, most participants enjoyed the design style, 'the idea of chopping tiles when placing a non-perfect piece is equally satisfying and annoying' and whilst the colours were 'nice', participants wanted the tiles to reflect the note they played (e.g., red tile for the note 'C'). Whilst participants reported enjoying the simple and calming nature of the backing soundtrack, others commented on wanting to have more impact when playing each note; reflecting that the backing track should match what is being practiced.

Usability

Once participants had understood the concept, which almost all did due to the simple mechanic, they found the game quite easy. The overall speed/difficulty of the game did not increase gradually (to try and keep participants playing to a set tempo), but participants struggled to focus on too many concepts at the same time. Observing the playthroughs it was apparent that keeping in time whilst playing out a tonal pattern (the scale) was already challenging for some. In addition to this, participants also needed look at the screen to place tiles. This led to frustration when trying to look at too many places all at once, as one participant reports, 'Annoying about focusing on the screen whilst trying to play' whilst another notes, '[it was] disconcerting when you get a tile placement wrong'. A positive response stems from how easy the menu was to use; participants could see the result of changing options on the screen in real- time.

Enjoyment/Engagement

Participants reported that it was easy to use and had an 'addictive quality' but eventually the concept 'would get boring' because it is simply repeating the same mechanic. Participants wanted additional features such as going up and down rather than constantly going up and more focus on the performance of a learner, '...more like score attack about how I performed'. Finally, most participants stated that they would prefer previous games as they offer both fun and some educational value right away.

Crossy Notes

Below is an analysis of the fourth prototype game, Crossy Notes in which the results are discussed based on the pre-defined categories of scope, design, usability and engagement.

Scope of Game

One of the recurring themes regarding the scope of this game was that it needed to be broader, '[Crossy Notes] lends itself to a broader range of objectives' as well as the game being more about 'fluid movement', which reflects playing keyboard. Although participants could use two hands, most found themselves finding this difficult as, 'Left and right controls make it more of a game but less of a music game because hands are in weird positions'. However, most participants agreed that this would be a fun way to practice concepts such as scales or notes on a staff; a good number of participants commented that the roads/lanes look like a staff so were confused when the game did not play as they figured it would, 'Could be

confusing as it looks like a staff'. Participants also wanted the sound of the player 'jump' to be the actual notes they played to help reinforce audiation skills, 'useful to hear the notes properly, game sounds are nice but use piano!'.

Design

In terms of sound effects, participants reported that they enjoyed the 'arcade' sounds, such as the cars beeping and the jump sound of the character. As this game is based on an existing theme, participants were happy to accept this and welcomed the idea of such themes; most participants commented that this would be ideal for children but would prefer to see something a bit more abstract was it to be aimed at their age range. As this was based on existing games, participants also wanted to see more design regarding the character, 'Better to have a frog than a cube!' Participants also reported that there was much happening on the screen; the original game is a simple mechanic of one press and this game is more complex than this, so, attempting to marry these two concepts may have led to unnecessary confusion and a lack of educational impact.

Usability

Observing participants, it was apparent that the aim of this game was difficult to grasp. The concept of crossing roads and avoiding hazards was simple but when combining this with having to play a note, participants became confused, especially due to the fact the game looks similar to a musical staff. In addition to this, the speed of the game was too quick to begin with and participants did not want this to speed up over time; 'start slower!' one participant commented. One of the biggest frustrations revolved around when and how participants failed; when getting hit by an oncoming car or playing the wrong note ended the game. Participants struggled to actually acknowledge this and tried to carry on playing. What was clear from this game was that the keyboard was seen as more of a toy, '[the keyboard] is like a game controller, you do not really look at it when playing!'. Comments such as this help to reiterate the direction the research must go in next. The lack of options was deemed a positive aspect as participants could jump straight in.

Enjoyment/Engagement

Nearly all participants found this game enjoyable to some extent, as it received the highest Likert score rating for enjoyment, indicating that this game was deemed fun though, confusing in regard to the actual learning objective. Participants commented that this was 'more of a game' and that 'the music was fun and enjoyable', and 'the most addictive'. Participants also

mentioned the idea of using levels rather than an infinite-based mode, i.e., the idea of having something to work towards was more motivating than trying to beat a high score each time.

Favourable Games

As mentioned, part of the post play interviews asked participants to give Likert scores regarding each games educational value and enjoyment. Whilst this is quite a subjective method of assessment, enjoyment was defined by asking participants how much fun they had in comparison to playing a typical video game or whatever their typical recreational activities were. Educational value was defined as how useful it would be for each participant when using the tools in conjunction with their own learning methods and whether or not they would seriously consider the practice of these skills beneficial to their playing. Not surprisingly, the games which focused on existing video games were deemed the most entertaining but lacked the educational aspect and vice versa for the games which resembled more of a learning exercise. Whilst the margins were rather slim, it was evident that the boundaries needed to be pushed further whilst also focus on assessment methods which were not so subjective and could be replicated by other researchers, i.e., there was a need for more empirical methodologies and to ensure the methodologies could be highly reliable and validated.

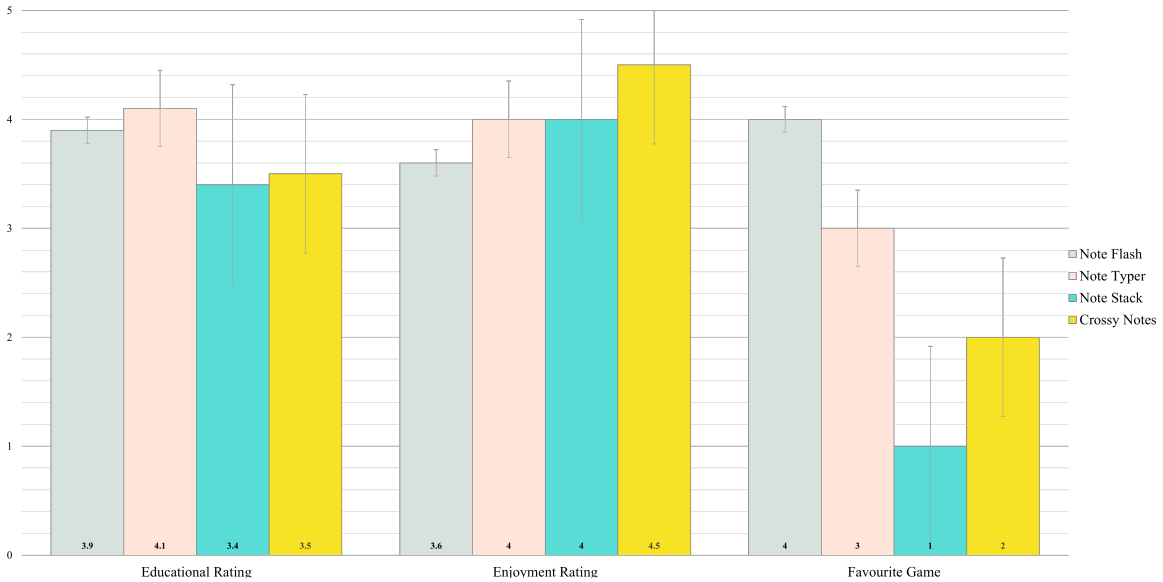


Fig. 4.10 Educational, enjoyment and favourable game Likert scores for each game that was featured in the study

Each participant was also asked what their favourite game would be and if they could offer insights and reasons as to why they chose a specific game. The two most popular games were Note Flash and Note Typer. Reasons provided relate heavily to how beneficial they are

to improving musical skills as well as being ‘simple and effective’. Both Note Stack and Crossy Notes received at least a vote for the favourite game question, but most participants stated that this was because they looked most like a game and would only use them if the scope was defined, and the mechanics had been refined. Once again, participants wanted the solutions to resemble games more so but needed them to be just as educationally valuable as their typical practice.

4.4.3 General Data Overview

There were some overlapping themes and changes which could be applied to all prototypes and considered when developing additional concepts. This includes:

- Showing an on-screen keyboard to demonstrate scales, notes etc.
- Feedback the correct answer when a user plays an incorrect one in order to encourage progression and improve overall effectiveness of the education
- Each game requires some form of acclimatisation if there is to be no researcher interventions, simply adding a tutorial is useful but further developments should try to implement lessons throughout and balance the difficulty based on performance of the individual player
- Menus and UI need to be simplified in terms of options and how obvious each option change is

Finally, participants were asked to rate how likely it was that they would recommend the game to a budding learner, all participants scored either 4 or 5 out of 5. When asked to rate how likely they would be to use the tools themselves, all participants said that they would be very likely to with some participants stating that it would be great for purposes outside the typical lessons, ‘A good use would be for travel’. Finally, all agreed that focusing on the practice of these specific skills would encourage them to play more and find more enjoyment in doing so.

4.4.4 Discussion of Results

Below is a discussion of the results from the initial pilot study, in which details are disclosed about the research position and the impact this research can potentially have in this field, the limitations of the study and how this reflects the future of the games and studies.

Establishing Research Position and Impact

Through the interview process, it was proved that learners (especially during the early stages) struggled to maintain consistent practice, and this led to negative connotations around playing. Moreover, the skills that had been defined previously such as, reading notation, rhythm control, hand and finger dexterity and audiation were all skills the participants wanted to improve but had no real engaging way to do so. Not only this, but teachers had also clearly stated that if they could offer their students a way to practice specific knowledge and skills which related to their most recent lessons, it would likely lead to more consistent practice and increase longevity of a learners journey.

It was realised that this style of learning will likely always be more engaging, however it was uncertain if it would be able to improve a skill and this type of practice would have real world application. Therefore, the future iterations and developments must narrow down a specific area of learning so they can begin to definitively state that the act of playing a game can actually improve a specific skill or area of knowledge. What was found through this study is that all participants were at least familiar with what a musical staff looks like and there were many comments revolving around the idea of adapting the games to look more like one. On top of this, it was established that all the games lack a sense of music, so this was kept this in mind for future developments; adding rhythm and basic melodies in which the developed games primarily use the musical staff as a basis of a design and educational goal.

Study Limitations

As this was an early and formative study, laid out below is specific criteria to take into consideration for future studies and assessment of novel learning games, ensuring other researchers do not make these mistakes and pitfalls. These changes include:

- What is measured needs to be more specific and replicable (i.e. less qualitative). Of course, the nature of this project still requires large amounts of qualitative data, but efforts must be made to ensure that next time the idea of testing ‘enjoyment levels and educational value’ has specificity, regarding mechanics and design choices, (e.g., how to measure ‘flow’ and ‘difficulty curves’ more accurately and empirically)

- In regard to measurements, it is important to measure the actual aim and scope of these games more precisely through developing games with more specific educational objectives and running studies which focus on skill and knowledge tests

- Keep exploring the emergence of new user studies found in both literature and on the market
- Each participant played the game for a total of five minutes, the choice to make the play time small was due a lack of content to test this early on. Future studies should ensure that playtime is longer and less strict – measuring how much a participant wants to play the game outside of a specified time window gives great insight into how engaging the game is without the need to ask the question directly
- Because this was a rather open-ended study with only qualitative methods, validation of the questions was lacking, and it was difficult to ensure reliability of the study. Going forward, it is important to consider others works for measuring items such as engagement and educational potential which would increase validation whilst also ensuring that analysis takes into account reliability of the questions posed – ensuring that what is found is true regardless of whom would be asked

Considerations for Future Games and Studies

The study showed that the games which were the simplest in design yielded the most positive results in regard to how educationally valuable they can be. Taking this onboard, it was decided that the best course of action was to focus on the two most popular games: Note Flash and Note Typer and build additional prototypes which consider these design choices.

A list of desirables to focus on in regard of improving existing prototypes and building new ones was constructed, this was derived from both the study as well as through reflection and play:

- Focus more on the use of music games and game design theory; as these developments focused on casual games, but these do not offer enough depth by themselves, combining additional features from music games and incorporating more game design theory should help create highly challenging and engaging games
- The challenge (i.e. the learning objective) is what drives engagement; adding elements of rhythm and relating back to music will help create diversity, challenge and depth
- Design work was needed not just related to visuals but heavily on the sound effects too; they need to be representations of notes and chords in order to help build audiation skills
- Focusing on a specific area of knowledge (sight-reading and rhythm) is key whilst also implementing additional exercises/levels/mechanics, such as the pattern of notes

spawning, in order to create additional ways of improving muscle memory, audiation, tonal patterns within an existing learning system

- More attention needs to be paid towards the actual use of gamification. Creating a list of features that the game should have adds structure to the development, as well ensuring that it is supported by tried and tested methods found on the market

4.5 Future Considerations

Narrowing down the right type of game and finding the balance of pedagogical value with typical game design is a tricky process - perhaps one that does not really have a satisfying conclusion. It became clear that this solution was novel and recognised by teachers and students as an ideal solution to the issue of high drop off and low engagement, especially with further refinement of each prototype assessed. Furthermore, the use of video games in this setting was most appropriate but what was missing was scope and standardisation as there as lack of any concrete conclusions of the potential for each game. The games were subjectively rated and it was clear that this method of learning would yield higher amounts of engagement but how can one assess both pedagogical value and engagement through more empirical and quantitative methodologies was a key question to take from this section of research.

The desire was to go beyond the work found in this area of research which typically focuses on specific use cases of custom developed solutions which are only applicable within a specific setting. Going forward, the research focused on a specific area of learning, the skill of reading musical notation – further detail regarding the reasoning for this choice and the steps taken that led to it is discussed in the next chapter. Current prototypes were improved and new ones were developed with this specific skillset in mind. Additionally, the study needed to be improved as well as methods of assessment, which required focusing on a specific skill to measure a games ability to improve it. The idea was to take the most appropriate prototypes forward and create new ones to add enough content and usability so that the games can begin to be tested on a larger scale without the need of a controlled environment, such as large-scale surveys and longitudinal experimental studies.

4.6 Chapter Conclusion

In this chapter, details of each mini game which made up the suite of mini game were delved into and was used in the first study. The study sought to validate the solutions by interviewing

and observing teachers and learners of mostly keyboard and piano from various skill levels. Through analysis of the data, using mostly qualitative analysis techniques (thematic analysis), it was determined that the approach and mini game suite was unique and accepted positively by both teachers and students. However, there was a need to objectively determine whether or not the games could be pedagogical valuable and engaging in real- world settings. Thus, the future direction eventually became targeting a specific skill area, the skill of reading musical notation – later defined as the skill of mapping physical keys to specific notes a musical staff. In the next chapter, reasoning behind choosing the skill of reading musical notation is outlined before discussing the relevant games and their development which had been chosen for the purposes of improving the aforementioned skill. Finally, the next study is described which sought further objective validation of each game and how this led to the final concept, 'The Crypt of Notation' and a remote, longitudinal study which was run in the final year of this doctorate.

Chapter 5

Reading Musical Notation Games

5.1 Chapter Introduction

Thus far, there were two key issues which were derived from the initial study and first set of games. Firstly, the games were not so much games but various takes on trainers found on marketplaces or in literature and were replacing simple existing mechanics with a simple learning objective, such as, tapping to a beat (they were not quite learning-based games). Secondly, each game was focusing on improving a different set of skills in which there was no way to determine if the game was improving that specific skill, especially using qualitative methodologies which lacked objectivity. The initial goal that had been laid out was to build a set of games to help practice specific skills, building a foundation for beginners to ensure that learning to play a piece of music was more attainable and demanded less cognitive load (i.e., associate practice with less frustration and increase the likelihood of continuing to learn to play). However, there was no framework to follow when designing these games nor did every skill have a robust method of assessment which could help ensure real-world application and focus on the transferability of that skill to other areas of playing or learning keyboard. Whilst a review of methods for assessing musical capabilities or aptitude as a whole had been conducted, mostly consulting the domain of psychology (Law and Zentner, 2012; Zentner and Strauss, 2017), these forms of assessment were more interested in general musicality rather than the specifics of learning an instrument or measuring a specific skill.

Therefore, the direction was to focus on acquiring or improving a specific skill in which a framework of design, development and assessment would be built that could later be applied to any other area of skill or school of learning. Using this framework, the future idea was to develop a suite of games which would then be used in a longitudinal study against a control group that uses traditional forms of practice, helping to determine whether or not

this game-based style of practice would have serious applications to learning and build skills which were transferrable to playing a piece of music.

In the pursuit to develop games for a specific skillset, the fundamental components of learning to play of piece music were reviewed, where some aspects were derived from the definition of musicianship provided by West (2015), but were also fairly logical. These components were rhythm (i.e., ensuring one can play to a set tempo and that their music flows correctly); executive skills which heavily revolved around using correct hand positions and fingering techniques to ensure that parts of a piece which were made up of faster notes or complex arrangements were able to be played fluidly and avoid injuring oneself; audiation which would help learners recognise if they were playing incorrectly by ear and to build further muscle memory between visual (notation), physical (the keys themselves) and sound. The final component, which was chosen to develop further solutions for, was reading musical notation (which later was defined specifically as the relationship between a physical key and a visual position on a musical staff). Whilst one could learn to play a song through audiation alone, for most adults who have a lack of experience, this is tricky. Although practising executive functioning skills, such as specific techniques to navigate the keys fluidly, is fundamental to playing a piece of music at the keyboard, it is irrelevant if one cannot read the music they see in front of them. Rhythm was inherently more enjoyable to practice than the other skills, highlighted by the fact that there is a huge industry for rhythm games alone; building practice games for this skillset was deemed redundant and our contribution would only be in the form of assessment in which there is already a large number of contributions. Finally, all of the skills except for reading musical notation, could be incorporated into a game and considered additional mechanics. For example, Note Typer was later extended to be played with rhythm in which additional points were rewarded for playing on the beat as well generating specific phrases to be played to improve hand and finger dexterity. The next round of development revolved around creating new solutions, and improving the current prototypes that were taken forward from study one, with this particular skillset in mind.

In this chapter the various games that were designed and developed for the specific purpose of improving a learners ability to read basic music notation are described. These prototype practice games fit into specific categories: basic trainers, gamified trainers, arcade style training and finally, concepts which portray video games rather than typical trainers found in the marketplace or literature (‘training games’). Through the process of iterative development, 6 solutions were developed which fit into the above categories. This chapter also outlines the second study which was conducted to assess the novelty of the solutions, pursuing a more quantitative and replicable approach to assessing both engagement and usability – using questionnaires which have previously been validated within this area of

research. Finally, as the participants for this study reflected the target population more accurately than the first study, further insights were gained into both learning and gaming habits – strengthening the argument regarding both the problem statement and the consequent solutions already developed. These prototypes and models of assessment helped solidify the idea that a practice solution should focus on one core skill whilst also incorporating other areas of music and skill which have transferability and application to real-world learning.

5.2 Notation Reading Games

Two games were developed further from the first round of prototypes: Note Flash and Note Typer. During this round of development, there was a decision to categorise each game into specific groups which have already mentioned - each group is described below in more detail as well as each game that was developed for that group. These categories were to help further determine the balance between an experience which is more of a video game and an experience which is a simple practice tool; categorising each game would help reveal which group was most appealing to specific learners/users and allow the development of games within that specific category (an attempt at organising concepts rather than developing individual solutions which had no real direction). For this phase of development, internal testing was mostly used before running a second study, which is detailed later in this chapter (see section 5.3). Below is a discussion of the key additional developments made at this stage; improving upon the limitations of the previous processes and taking into account the more generic lessons that were discovered in the previous study. Further details about the specific categories that were defined and each game that was developed for each category are then explored. If it was an existing solution then the discussion regards the additions developed and how the game was expanded regarding the design. For all developed solutions the key lessons that were taken into account based on previous insights are explained, as well as various inspirations that aided the design process and an overview of how the solutions are played with their various intricacies.

General Improvements

The same process was followed as the previous development cycle except with the focus on internal testing and validation rather than external. The focus on internal testing was followed for a number of reasons: it was cost effective; it was already established that there was a place for these novel methods of practice and there was high amounts of similarities between the first study feedback and the feedback received internally. The second study was

based on the six key games but the use of internal testing help to narrow in on these games, to help focus on specific designs and smooth out mechanics.

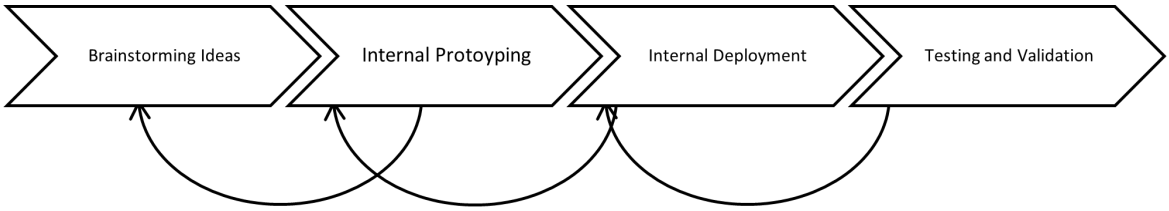


Fig. 5.1 Development pipeline for the second set of games, focusing on mostly internal testing and validation

Concerning the programming and the 'backend' of the prototypes, there was some refinement as well as some overall additions that were implemented based on the feedback gained. As much of the feedback revolved around including more music and rich sound effects the developments began to investigate the most efficient and effective way of implementing this. Initially music was sourced from open-source libraries and used samples of sounds which were played when playing specific keys. Typically, a sample that was chosen at a certain pitch (e.g., C5 would be the same pitch as 'middle C') then shifted the pitch depending on which key was pressed using a simple power algorithm (see below for further information). There were a few issues with this implementation: the songs found did not include their BPM making it tricky to build rhythmic elements, finding the exact sound effects proved tricky and the pitch shifting led to inconsistencies regarding the length of notes played (as increasing/decreasing pitch would naturally change the speed of the sounds). These issues were overcome with the incorporation of an in-house synthesiser into the project - using the Audiohelm plugin for Unity (Audio Helm for Unity, 2014). With this plugin, it was possible to load patches into Unity and play specific samples which had already been created (rather than creating new ones by manipulating pitch).

$$F = c * 1.05946^{n}$$

(a) Calculating the frequency of each note would require taking a base frequency, typically the lowest note possible, and multiplying it using the above equation; where c equals the base frequency and n is the number of semitones

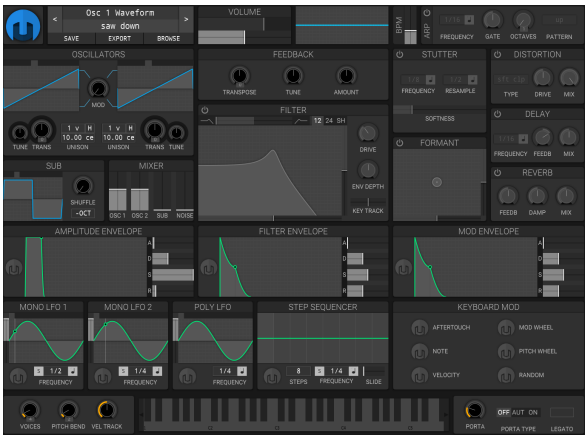
$$F = 1.05946^{12} == 2$$

(b) As demonstrated, if one sets the power to 12, the value equates to 2 (i.e., raising the pitch by a whole octave)

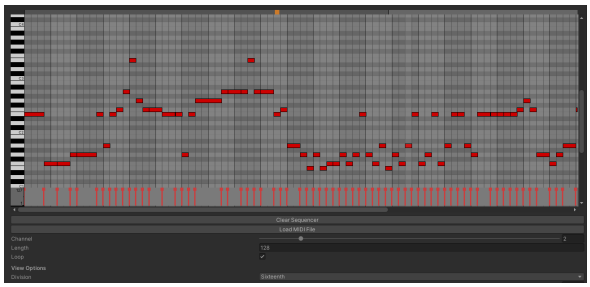
Fig. 5.2 Manipulating pitch by multiplying frequencies

The issue of rich music was solved by creating a simple but effective generative music system. The system worked by selecting a random note from a set of notes which could

be chosen by the user, in which there was a minimum and maximum number of octaves that the note could be chosen from (e.g., a user would input ‘middle c’ with a minimum and maximum number of octaves set to one and the system could pick a ‘c’ note from an octave above or below the ‘middle c’). There was another variable defined as ‘density’, that essentially defined how spread the selected notes could be – the higher the density, the more spread out the notes generated would be and vice versa. The plugin included a sequencer, where one could set the length of the generated song (typically in factors of 8) and the division of the length (again, typically in factors of 8) telling the sequencer how often to play each note (e.g., if it was a length of 16 and a division of 16 then a note would be played every beat without rests for 16 beats). Using the sequencer, one could generate a series of notes based on the length and this would be outputted to a specific audio channel. Later each game implemented multiple generators which would play bass notes as well as lead notes – setting the specific BPM for the sequencers to play to using a simple audio clock. Finally, specific drum patterns were created which would be chosen at random when generating the music and would add a steady drum beat. Combining multiple generators and a drum beat led to satisfising music with an obvious tempo, helping to play to the beat and improve basic rhythmic skills.



(a) Audio Helm’s standalone patch creator



(b) Audio Helm’s sequencer seen in Unity

Fig. 5.3 Audio Helm

Another major contribution to the development of the prototype games was ensuring that the music and metronome in which users would play to would maintain consistency, as it was found that the first set of games would often fall out of time and this would frustrate the players/learners. To overcome this required moving the components which tracked sound or tempo outside of Unity’s update method, a method that updates every ‘frame’ which can vary significantly for each device (a high-powered computer will have a much higher frame

rate than a mobile device, for example). This meant that each game could not rely on Unity for maintaining consistency of tempo for the games as it would eventually fall behind or become too fast. Therefore, these settings were based on more precise measurements using the Unity's Audio settings – this implementation was derived from an online guide (Tattersall, 2019). First, beats per second were calculated by dividing the provided BPM by 60 (i.e., a minute). Then, using the time that audio settings could provide, (Audiosettings.dsptime) which would measure time independently of any other methods within Unity, the beat per second variable would constantly check (using enumeration) if the audio time would go over this variable - if it did then another beat per second would be added to the same variable and checked again, constantly repeating this. Using this implementation, actions were executed or determined if the player was playing on time every time the time went over. This was extremely accurate and led to almost no inconsistencies which was great for syncing visuals over extended periods of time. However, because it was so accurate, it was quite tricky to actually 'play on the beat'. Therefore another variable called 'difficulty threshold' implemented, which would be a small fraction of time either side of the beat to allow for easier playing. This would later be used to add various scores to how accurate players would hit the keys on the beat (defining this as 'early', 'perfect' or 'late' depending on when the note was played).

Basic Practice Tools

The first category of practice solutions begins with the most basic premise learning based game and was used as the baseline comparison for the other games. These solutions are replications of simple practice tools found in the marketplace and focus on function with a lack of gamification or game design. During study one, the results indicated a positive response to simple practice tools as they offered a simple but effective approach to practicing a specific skill without the distractions of gamification. Essentially, the idea was to determine if learners preferred a simplistic approach to practice as it was inherently easy to understand and effective or would they prefer something which resembled more of a game; this category helped create a baseline of comparison to answer this question and to compare against more gamified approaches. This category features two solutions: Note Trainer and Note Flash, which are described below.

Note Trainer

Note Trainer is a tool which helps learners build familiarity of notes to physical keys and later to musical notation. This game is based on Note Flash, except with as little gamification

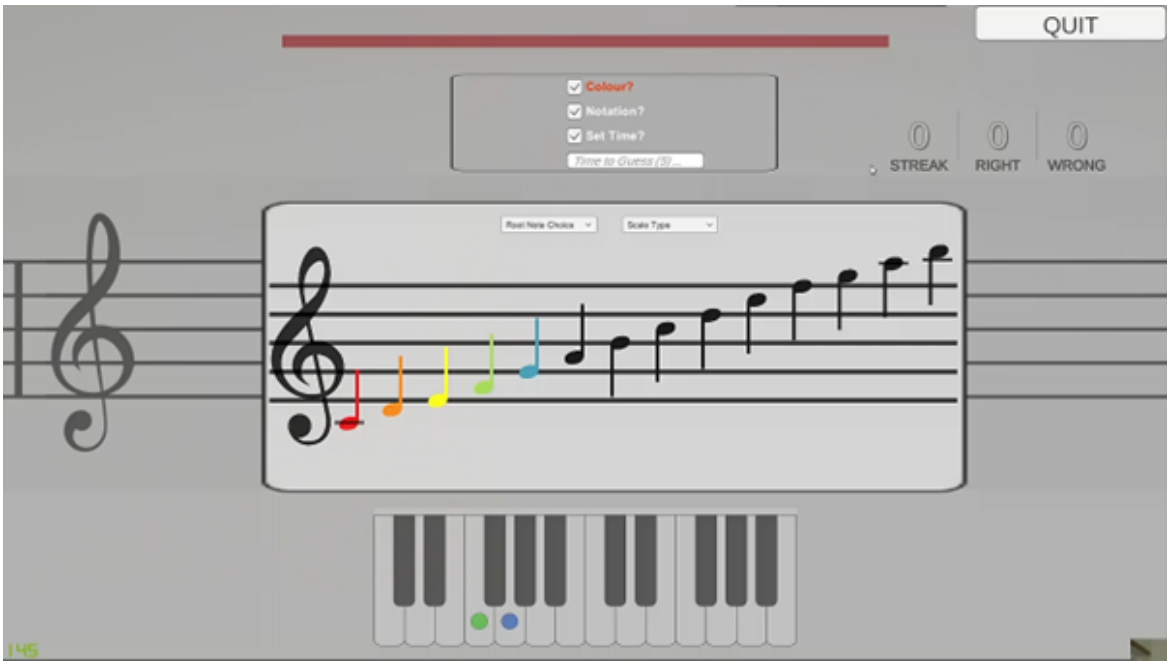
as possible and focused on the functionality of the tool more than the experience of the player (i.e., the opposite of gamification). Similar applications online were reviewed for inspiration, and it was found that they all followed a similar pattern of choosing notes to practice then being shown these notes (with the exception of some implementations (*Clefs*, 2020; *Jungle Music*, 2016; *NoteWorks*, 2012) which built a series of levels for players to follow and were typically aimed at children). Players could either choose specific notes or pick a particular scale in which notes would be randomly selected from. Players could also choose if they wanted to be shown the letter representations of the notes (useful for absolute beginners) or if they wanted to be shown notation. All of these representations could also be shown with or without colour (which was useful when playing in conjunction with the LUMI keyboard as the colours would match one another). There were three modes available: infinite mode where players would keep guessing correctly and get a game over if they get an incorrect note (how many notes in a row could they get); timer mode where players had to guess as many correct notes as possible in a specific period of time; clock mode where players had a small window of time to correctly guess and if it was correct then more time would be added onto the clock which would get increasingly more quick, eventually too fast to correctly guess. These modes with the addition of score (showing total correct, incorrect and correct guesses in a row – the streak) were the only main aspects of gamification. As the game was inherently simple there was no tutorial except for showing an on-screen keyboard which would highlight the correct key after a number of incorrect guesses.

Inspirations and Insights

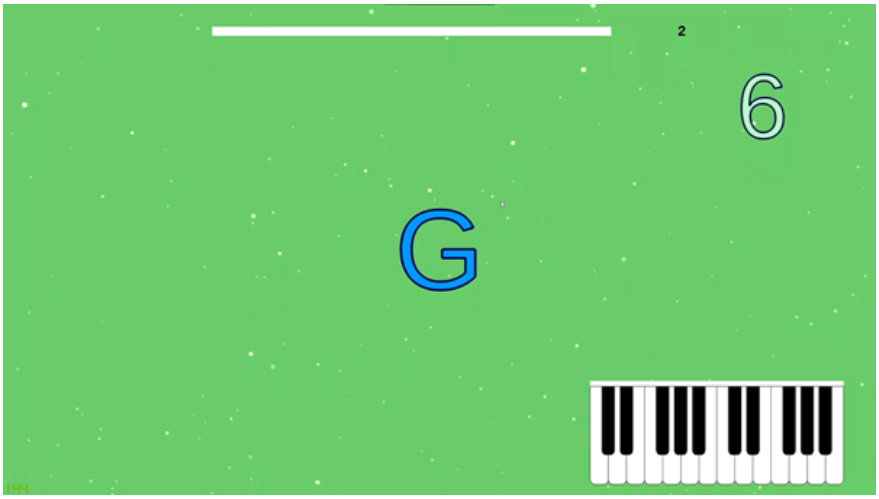
This game was heavily inspired by Note Flash and incorporated lessons from the initial study: an on-screen keyboard was implemented, the sounds were accurate representations of the note played and if they player continually gave incorrect guesses, they would be shown the correct guess on the on-screen keyboard.

Note Flash

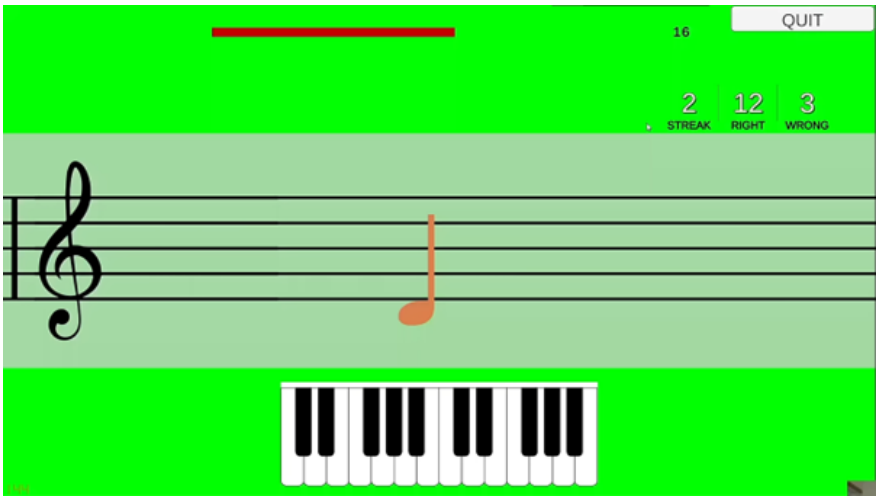
The development of Note Flash continued on from the first phase of development as it was one of the prototypes that was rated highest in all categories. Taking on board the feedback from the study regarding the desire of rhythmic elements and UI, an on-screen keyboard was implemented and a new mode which showed smaller notational cues in a circle. Players had to play the correct key when the ‘tempo bar’ crossed over the corresponding notation, in an attempt to incorporate rhythm (see screenshots for more details). An extension prototype was developed in pursuit of adding rhythmic elements to Note Flash, where notation is revealed



(a) Note Trainer menu: this setup menu was implemented for every game at this stage



(b) Note Trainer being used to practice note recognition



(c) Note Trainer used with notation and 'timer mode'

Fig. 5.4 Note Trainer screen shots

on a horizontal axis and a 'rhythm bar' moves from left to right – players must play the correct corresponding key to the tempo to score; the use the circle representation of rhythm appeared to reflect the concepts of rhythm more logically and allow fluid repetitions.

Inspirations and Insights

Whilst inspirations have already been discussed in the previous chapter, a review of more games for inspirations into incorporating rhythmic elements into Note Flash was conducted. This review was specifically concerned with rhythm games and found that using some form of visual for the 'tempo' was useful as relying on audio alone proved quite tricky. This idea of visualizing rhythm with the audio proved to be both a valid aid and a satisfying mechanic. Whilst most games create their own tracks and specific beats, it found it most efficient and pedagogically valuable to base the rhythm on simple but recognisable time signatures (which would add transferability to a learners practice). Finally, another common design in rhythm games was to increase the tempo over time (typically using the 'ascending arcs' design (Holleman, 2019)) but it was found that doing so would distract learners and lead to frustration when the action was overwhelming.

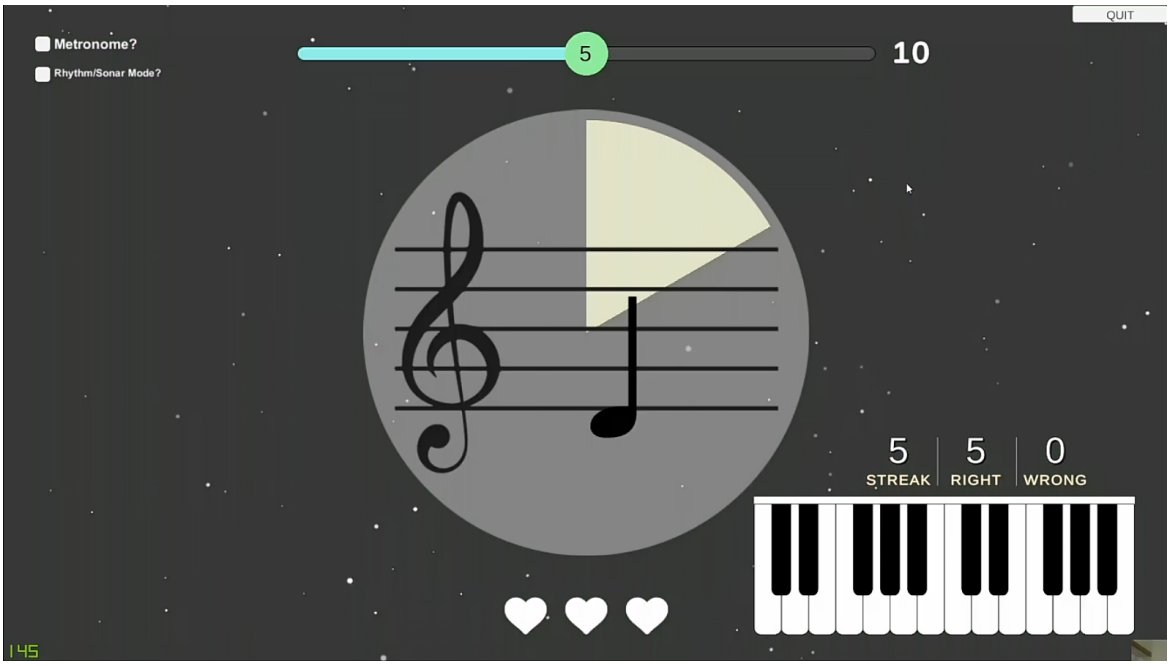
(a) *Sonar Beat*, a rhythm game in which the design replicates a 'sonar' graph

(b) *A Dance of Fire and Ice* a unique style rhythm game

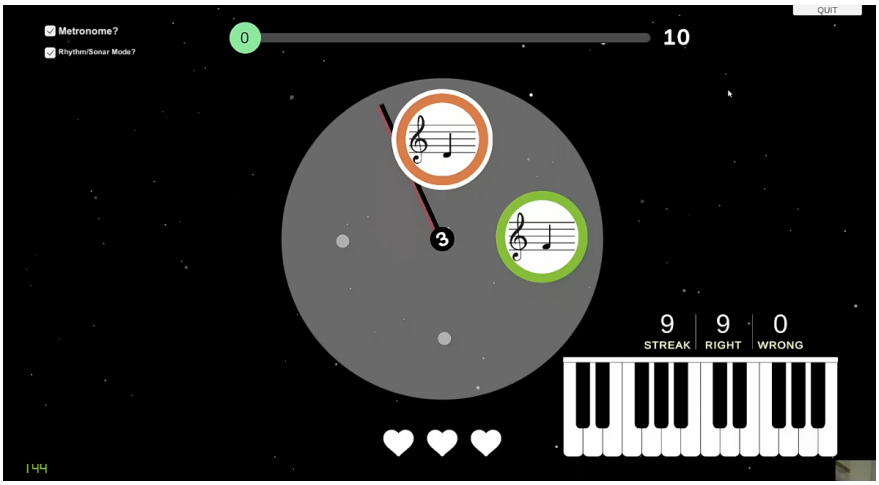
Fig. 5.6 Various Inspirations for Note Flash

Gamified Practice Tools

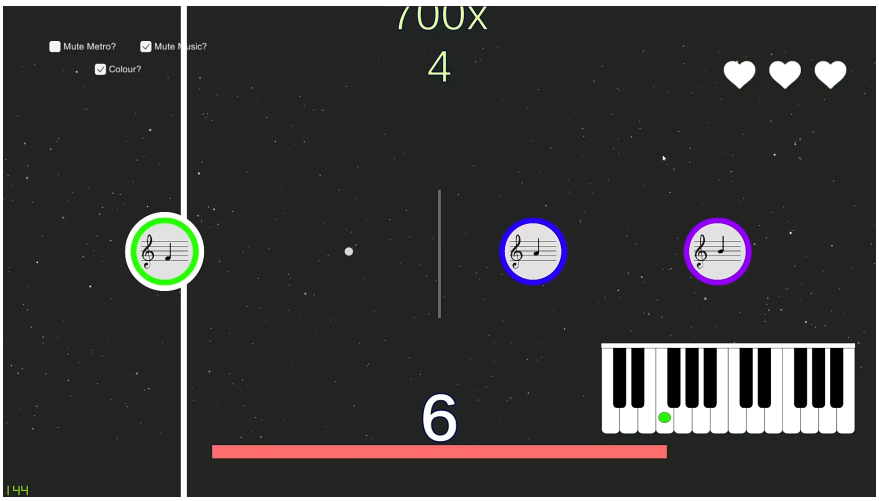
Whilst the basic trainers helped provide a baseline for comparison, the research also explored possibilities of gamifying them further and what effect this may have on engagement and pedagogical value. Several prototypes were developed in an attempt to gamify a basic version of Note Flash/Trainer. The end result was inspired by *ZType*, *Space Invaders* and based on Note Typer, which adopted a sci-fi style theme. Whilst there were other concepts developed for this category, which are shown below, only Notes Invaders was used in the study as it



(a) Note Flash being used to practice reading notation in ‘level mode’



(b) ‘Note Sonar’ a rhythm variation of Note Flash



(c) ‘Note Line’, another variation of Note Flash using rhythm

Fig. 5.5 Note Flash and Variations

was the most positively received during internal testing. In the below section Notes Invaders is described and whilst also briefly mentioning the smaller concepts that were developed and the other games that helped inspire this category.

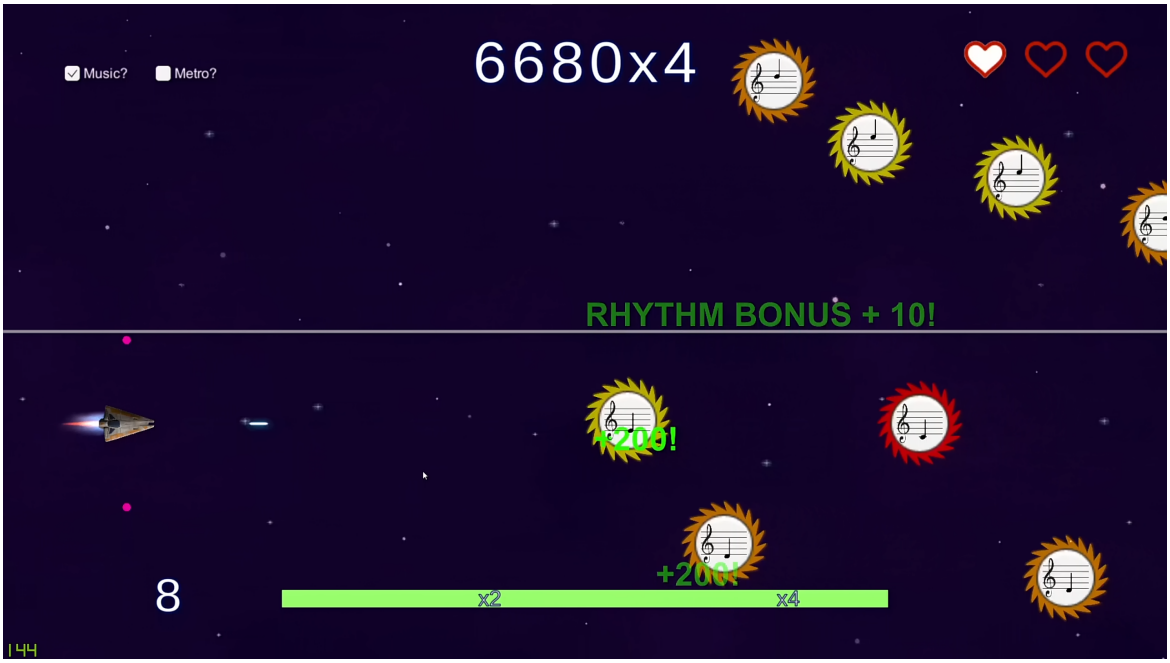
Notes Invaders

The original Note Typer game had notation/notes falling from the top to the bottom of the screen, however it was realised that to reflect a musical staff more logically it made sense for the notes to move from right to left (to reflect reading sheet music). The option to play with two hands persisted by splitting the screen horizontally and allowed lower notes (i.e., bass notes) to be played on the bottom side of the screen with the left hand and vice versa for treble notes. This was the first game that made use of generative music, which created a simple yet satisfying and bass driven chiptune style track from the notes that the learner was practising in their current session. The combination of the track matching the same notes as the learners were playing with a strong sense of rhythm made the game feel musical but still quite jarring (as the notes were random rather than a coherent and melodic pattern). To overcome this, notes were generated with set patterns which helped increase finger dexterity and build muscle memory whilst also adding additional juice (Hicks et al., 2019) and musical depth to the game. Later, the design of the game chosen opted for a sci-fi theme. The choice for this design was inspired by the main inspiration *ZType* as well as the arcade classic, Space Invaders (hence the game of this game). The notes were designed as 'hazards' which would flash to the beat and explode when their correct note was played (adding additional layers of 'juice'). The hazards would spawn in waves and if a hazard hit the player ship, a life would be lost (with a total of three lives to lose). Each wave the hazards would increase in quantity and speed. An error bar and a multiplier bar was also developed. The error bar would fill with each incorrect note played, resulting in a life lost once fully complete or would reset on a correct note - this ensured players could not 'spam' the keyboard to win every time. The multiplier bar would fill on consistent correct notes – the higher a streak, the higher multiplication of score (again, borrowing ideas from game design (Schell, 2008).

Inspirations and Insights

The game was based on a previously developed game, Note Typer as well as extending further by conducting a more in-depth review of the games mentioned above. The game also borrowed ideas from an online practice game which used a 'Star Wars' as the theme (Colin, 2016), which helped to decide on the sci-fi theme, albeit, without being specific to the 'Star Wars' franchise. One of the main takeaways from the previous study was that the

(a) In game screen shot of Notes Invaders



(b) Notes Invaders being played with two hand mode: using higher and lower treble notes

Fig. 5.7 Notes Invaders and Variations

'hazards' (the notation) moved at different speeds and were appearing at different rates. Tying this in with the need for a musicality, the notation spawn to the tempo/BPM of the backing music whilst ensuring that the notation move consistently to the music also. Difficulty could be raised by either increasing the BPM or the length of the notes to reach the player (for example, rather than quarter notes, one could use eighth notes which doubles the speed). Whilst the previous study determined that the exploding notes were an exciting addition, they were too bulky and would cover the oncoming notation too much. Therefore, the design of the explosions were changed so they were less intrusive and dissipated faster. A final change was related to the design of the 'phrases'. Initially phrases spawned as one object - in the new version only single notation is shown but are spawned in patterns – this reflected the feedback from the initial study in which participants enjoyed the patterns but found them difficult to read.

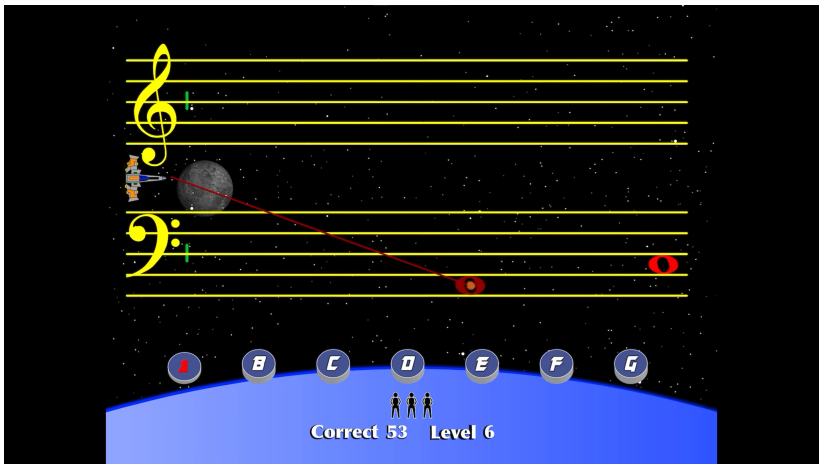


Fig. 5.8 (Colin, 2016), a notation reading practice game based on Star Wars themes

Arcade Practice

This category was an attempt to bridge the gap between video game experience and a practice tool by creating 'old-school' style games which would offer meaningful practice. A key takeaway from the first study was that most participants were familiar with the visual representation of a musical staff and could recognise it even if they were complete beginners, furthermore, they naturally associated the musical staff with learning and playing music. When reviewing rhythm games, it became apparent that a lot of them were based on 'lines of beats' in which the objective was to hit oncoming objects to the time on a specific line. It only logical to try and mimic this but use the lines of a musical staff as the main basis of design. Ideas were borrowed from other games (*Bit.Trip Beat*, 2020; *Tadpole Treble*, 2016) where one would glide down a line on the and shift up and down to different lines to avoid

incoming hazards or collect items. Multiple concepts of games were developed that were based on staff and found that it was significant step forward to becoming a game, albeit in a simpler fashion which was akin to games to found in arcades – hence the name of the category. Whilst this category only features one game, Staff Arcade, this game is made up of smaller mini games (which is derived from the games reviewed previously which use this mini game format). Below is an outline the overall process of making the arcade and the five mini games that are featured in the arcade.

Staff Arcade

Staff Arcade is a collection of smaller mini games all based on the musical staff. The original idea was to take a previous prototype, Note Shooter, where players 'shoot' objects down lanes which correspond to notes of a scale, and apply it to the musical staff. This translation appeared highly logical and was in line with the feedback received during study one: participants wanted higher transferability of each game to real world applications (i.e., a reflection of what playing and learning would look like). Essentially, the premise rather simple: put the player on a specific position of the staff and allow them to move from one position to another by playing corresponding notes (basing the design on a strong core loop (*Core Loop in Game Development*, 2019)). There were two mechanics that allowed this movement: one was a teleport mode where the player could press any key and move instantly to that location and 'adjacent mode', in which the player had to play the note adjacent to the current one they were on to move up or down (for example, if they were on a 'c', they could either play 'e' or 'd'). Later, scales were implemented forcing the player to only play notes which were part of a scale and could include sharps and flats, for more experienced learners. All mini games made use of the generative music system as well as the rhythm components, spawning notes to a specific tempo and ensuring they move smoothly to the backing track. In all mini games, the player object (represented as a whole note) would have two dots which would move back and forth and represented the visual of rhythm. As with all of the games, if the player correctly scored with rhythm they would earn extra points. With some of the staff mini games, there was an option to 'force rhythm' where players were required to play on the beat rather than just being offered additional points. The game also featured a lives system, typically allowing five lives lost besides from two of the mini games, which are mentioned below. Five mini games were developed as a part of the arcade:

Staff Shooter was the first mini game developed and involved firing at incoming 'hazards' which would be spawned on specific positions on the musical staff. They were two design options that were developed: one would 'explode' notes when correctly guessed

and the other would ‘colour’ notes; notes would spawn white and if they were correctly guessed their colour would change to that of the colour of the key on the LUMI. If a note ‘hazard’ reached the left-hand side of the staff before being played, this would result in a life lost. As with Notes Invaders, if they player had earned a streak this would result in a multiplication of score. Also borrowing from Notes Invaders, notes would be spawned in particular patterns to increase musicality and help improve hand and finger dexterity

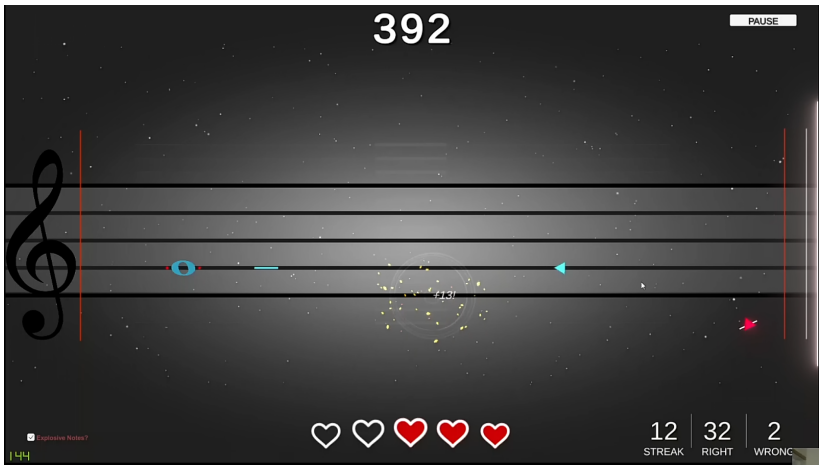


Fig. 5.9 Screenshot of Staff Shooter

Staff Dodger was essentially the opposite of Shooter where players would avoid or ‘dodge’ incoming notes by changing their position on the staff. Bonus notes were spawned to increase the agency of the game – by collecting these notes and narrowly avoiding incoming hazards, the players would earn additional score. If the player was struck by an incoming note, they would lose a life. This game was particularly engaging when combined with ‘adjacent mode’ as players had to plan their moves wisely

Staff Catcher was the friendliest of the games and involved ‘catching’ the incoming notes. A life would be lost if a note was missed and hit the left-hand side of the staff. This game was elevated by ‘adjacent mode’ and also made use of musical patterns – the notes would move to the tempo of the backing music and players would collect each note on the beat. As opposed to having to try and play on the beat, this game ensured that the notes were played on the beat every time they were ‘caught’ which led to a great sense of musicality

Crossy Staff was developed from the original game ‘Crossy Notes’. Essentially, a series of notes could be entered to practice and players were required to play the pattern in an

ascending and descending manner, whilst avoiding incoming note hazards (typically using major scales as the note series). This game was great for building particular finger techniques, such as the 'thumb under' technique as well as reiterating particular scales or musical phrases – all of which required a basic understanding of reading musical notation. This game offered only three lives as internal testing sessions typically lasted too long and became a bit mundane; by decreasing lives and increasing the exponential increase of difficulty, a good balance of satisfaction and frustration – helping players to find a state of 'flow' (Engeser, 2012)

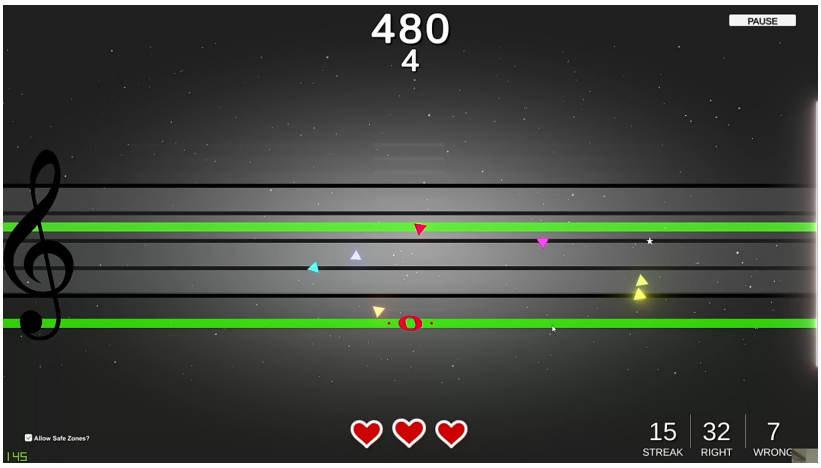


Fig. 5.10 Screenshot of Crossy Staff

Shifter and Shapes was the final mini game developed and focused on improving finger movements whilst also building stronger hand positions. In 'shifter' mode, players would pick a series of notes they wished to practice and a 'blocker' would begin to move from right to left; the 'blocker' was made up of a series of red blocks in which one was green – it was up to the player to 'shift' to the green block position or lose a life. This game mode was played exclusively with 'adjacent mode' as teleporting made it a bit too easy. The other mode, 'shapes', was similar in nature but used multiple green 'blocks' which required the player to hold down multiple notes to fit through the 'blocker', requiring particular hand shapes which would improve hand dexterity, typically used to play chords

Inspirations and Insights

Some of these concepts were based on existing solutions previously developed. For example, taking Note Shooter and applying it to the musical staff, and Crossy mode was a take on the original prototype, Crossy Notes. However, the idea of placing these games on the musical

staff was both based on feedback from the first study but also on existing games that were reviewed.

(a) *Tadpole Treble*, a musical runner game based on the musical staff

(b) *Rhythm Doctor*, a game which requires precise rhythm

Fig. 5.11 Inspirations for Staff Arcade

The additions of live systems, music and rhythm as well as more intricate design ensured that this category games was a step forward from the previous concepts. Finally, rhythm games were consulted (*Bit.Trip Beat*, 2020; *Rhythm Doctor*, 2021) heavily for the development of the arcade. These games were all similar in mechanic, where players were required to hit objects at certain positions to a set beat. Combing the feedback from study one with the gamified training tools and the rhythm games led to Staff Arcade, which was believed to be a novel concept in this area of both practice and video games.

Practice Games

The final category of games is where the research finally begun to break through into concepts which represented video games more than gamified practice tools. For this category, inspirations were based on popular games in the marketplace, considering multiple genres that would help build a foundation to broaden the existing solutions. Looking to RPG and action style games whist also reviewing games which had taken the idea of rote learning, primarily typing games; games such as *The Typing of The Dead: Overkill* and *The Textorcist: The Story of Ray Bibbia*, which had been around for some time and were immensely popular. Newer games such as *Epistory - Typing Chronicles* added more depth and complexity to the simple core loop of typing words by implementing levelling systems, unlockable skills and player customisation. Looking to rhythm games, similar patterns emerged. Whilst rhythm game were inherently simple, there were other games such as *Crypt of the Necrodancer* that had extended the genre by combining other genres, such as RPG and roguelikes. Being inspired by video games without a serious application helped define a unique edge when it

came to development. The core loop was always rather simple but the additions of narrative, levelling, currency systems and other classic video game tropes helped to enhance these experiences and create novel practice solutions. Whilst there were multiple ideas for this category, it was decided that a game within the RPG genre would be developed. The choice of the RPG genre relied on the fact that it was recognised by gamers and non-gamers, the design was interchangeable to meet specific player types and the array of mechanics and features was almost infinite – it provided a platform. Finally, this style of game could also benefit from merging with another genre, roguelikes. This combination of genres allowed content to be procedurally generated and offer a lot of replay ability; thus reducing the need to develop very specific content and allowing developments to focus what was most important.

There were four main concepts designed and considered for development: a turn-based top-down game, an FPS style game, a platform game and an RPG game. Each design was based on existing solutions, for example, the FPS style game was derived from a typing game, *The Typing of The Dead: Overkill* and the top-down game was derived from *Hotline Miami*. Whilst each game would be unique and help to develop novel solutions, the decision was to only take the RPG game forward.

Music Graveyard

Music Graveyard is an RPG-style game which focuses on a main character, Maalik – the cat guardian of purgatory, who is trying to dispel the evil found in a fictional graveyard by 'playing funky beats' and bring peace once again to the afterlife. Players progress through a series of levels by destroying specific objects (crates, pots etc.), defeat enemies and resolve basic puzzles by using their knowledge of reading musical notation.

(a) Concept design of Music Graveyard

(b) Early build of Music Graveyard

Fig. 5.12 Music Graveyard Early Concepts

The core loop is essentially to learn the notes throughout the level, gain skills, powerups and attributes which will then help you defeat the final boss/scene. Players should be reinforced in this regard by wanting to find the secrets, coins and powerup, not just because it is satisfying, but because it will help them beat the level (Colby, 2019). The core loop and secondary ones are reinforced by rhythm and players should want to play in time earn extra score/XP. Obvious and typical traits are found throughout the game – follow a series of patterns to unlock something, place a block on a button, scenes of agency where players must navigate difficult paths with speed. Players can switch from 'move mode' to 'read mode' – in 'read mode' they can see all areas of interaction with notation. As this game was rather extensive to develop, a useful tool that was used was the MoSCoW development framework (Spiru et al., 2019) to ensure that time was not wasted on over designing specific mechanics or complex designs.

Inspirations and Insights

As mentioned above, there were many games were used for inspiration to develop this game. However, there were a few key games that were used to base a lot of the design and mechanics on. Notably, this was *Epistory - Typing Chronicles* which is a very similar concept, albeit this version is played with a MIDI keyboard and incorporates music in a more involved manner. Other particular action and RPG style games were reviewed, including *Figment*; *The Touryst*; *Wandersong*) to help define a clear narrative and inspire the theme of the game. Finally, two roguelike rhythm games were used *Cadence of Hyrule*; *Crypt of the Necrodancer* to help design the theme and also implement rhythm into the game. These two games were key inspirations where ideas of narrative, health system, currency and various puzzle mechanics were borrowed and applied in their own fashion to this game.

(a) *Epistory - Typing Chronicles* (b) *Crypt of the Necrodancer*

Fig. 5.13 Inspirations for Music Graveyard

Fig. 5.14 Newer development of Music Graveyard

5.3 Assessing Notation Reading Games

The six games were used in a new study, building upon the limitations previously discovered: most notably using existing questionnaires to measure the aspects of usability and engagement which would lead to higher reliability and validity. The play time for each game was increased and were less strict which would help make observations into which game is more engaging purely by comparing total time played and overall reception. Each game had various mechanics and design choices, and through this study specific could be narrow in and deemed the most appropriate for the target population. The study would help to narrow in on one or two concepts which would later make use of the highest rated and most generalisable mechanical and design principles. This assessment would help establish how far one could gamify practice, using the finalised developed games within studies that reflect real-world application and measure pedagogical aspects in a standardised and objective manner. Finally, whilst participants did share similarities in their gaming preferences and habits, there was conflicting opinions of preferences which naturally arose through this process. Through this study it became apparent which genres of game could be most applicable to a wider audience and it was important to define the target population further, resulting in a niche but loyal audience which would be easier to retain for longer periods of time.

5.3.1 Intended Outcomes and Questions

- Ensure methods that assess both usability and engagement were robust, valid and could lead to high reliability that could be used in future studies
- Ensure the educational aspect of the prototypes are clear, accurate and meaningful, identifying any additional facets of the main issue
- Ensure user experience, overall usability and difficulty is suitable (i.e. not too difficult or too easy and can be played without researcher interventions)
- Narrow down specific mechanics and designs in each concept such as levels (and progression) vs. infinite, the use of music, important UI decisions etc. (a full list is available outlining each key decision for each prototype)
- Use suitable observations and insights to narrow down to one or two game concepts

5.3.2 Participants

The initial sample comprised of 17 participants (5 females) aged 25-64 (with the majority of participants aging from 25-34 (70%)). In total, 8 participants (47%) were musicians who had at least 5 or more years of experience, 10 participants owned a key based instrument which was mostly a MIDI keyboard and 9 owned either another or second instrument (this was typically a guitar but with some more niche instruments including a flute, cornet and cello). Out of those that were not experienced musicians (i.e., less than five years of experience), there were some lapsers (N=3) who had typically played music as a child and had not attempted to learn since. The rest were novices who were either absolute beginners (i.e., no experience whatsoever) or beginners who had been playing for less than a year. The novices had a desire to play keyboard or piano – mostly stating that they wanted to play their favourite pieces rather than become producers or composers. As the initial invitation was seeking aspiring musicians (particularly pertaining to key based instruments) who were already interested in video games, all participants, except for one, were avid video gamers.

The majority of participants played video games at least once a day and would play for over an hour, however, all of them stated that they used to play a lot more but struggled to find time for consistent and longer sessions as their responsibilities became overwhelming as they grew older. Participants were also asked why they played video games and the results were remarkably similar. They were playing for reasons of escapism, immersion, stress relief and enjoyment; they were seeking ways to unwind after a long day, as they were raised with video games from childhood, it was natural for them to use them in this capacity.

Table 5.1 Study Two Participant Demographics

	Age Group		
Demographic Information	25-34	35-44	55-64
N (Count)	12	3	2
Gender (count)	3F(25%)	0F	1F(50%)
Use Applications To Learn Keyboard (count)	4Y(33%)	0Y	1Y(50%)
Video Game Player (count)	11Y(92%)	3Y(100%)	2Y(100%)

Regarding each participants methods of learning, there was some variation and most participants stated they had used multiple methods. The majority of the experienced musicians had used a teacher at some stage in their learning or had enrolled in music during school, typically being pressured by parental figures to do so. Intriguingly, the lapsers had stated that they were pressured to learn and this led to them dropping out - those that had carried on even though they were pressured claimed they had found a niche area of music which they were passionate about (for example, switching from classical to jazz pieces). The second most common form of learning was reading music books and self-learning. The majority of participants stated that they had used learning applications but did not find them particularly useful and preferred either YouTube videos or dedicated practice tools. When asking what their typical method of practice would look like, the novices would attempt to play simple songs or parts of pieces they enjoyed as well practicing scales, reading notation and using examples from books or friends. All novices stated that it was a struggle to consistently practice and would often miss sessions they had planned due to time constraints or because they simply wanted to pursue less demanding recreational activities. All of the participants were excited by this novel solution to mundane practice and would relish such a method of practice if they had the chance.

5.3.3 Study Procedure

Participants were recruited via email using existing mailing lists of the placement company which were made up of previous user testers for various hardware and software, most recently, the LUMI. The study was conducted in the company's main offices – most of the previous users were locally based and those that had signed up were aware of the commute to the office. To ensure that enough participants were recruited, an incentive in the form of a £20 Amazon gift voucher was used in advertisements. The initial date of the study continuously changed due to the Covid-19 epidemic that prevented working in closed spaces and interacting with those outside of small groups of friends or family. After delaying the study for around two

months, the rules and regulations had changed, giving the ability to run the testing, provided specific safety regulations (see chapter 4, Covid-19 policy for details) were adhered to.

Once participants had signed any required forms and were comfortable with their safety and information being shared with the internal research team, they were asked introductory questions that gave background information regarding music experience and gaming habits of each participant. Participants were sat down in front of a screen (in this case, a laptop running Windows 10) before the play session. Each participant was guided through the process of the study and they were required to setup each game whilst being offered minimal or no instructional help (only if they requested it) – it was important to measure usability of each solution and ensure they could be used outside of a controlled setting. All users were allocated ten minutes to play each solution and were instructed that they do not have to play for the full ten minutes or can go over the time limit (this open-ended approach provided valuable insights into how engaging each game is). Real-time observations were conducted throughout and participants were asked questions regarding the preference of certain mechanics and design choices during gameplay, as well specific questions after each solution had been played. Their responses, and their play style using the keyboard, were recorded via a webcam recording and *OBS* was used to record the screen.

A major challenge the research was facing when assessing the novel games was determining their 'enjoyment' or engagement and understand the motivational dynamics of each developed game. This was reflected in the limitations of study one, in which simple and rather open-ended questions of 'enjoyment' from the participants perspective. Through reviewing literature for robust methods of assessment, a popular theory and consequent questionnaire was found that was used for assessing such an abstract concept. This was the Player Need for Experience (PENS) (Rigby and Ryan, 2007). The PENS is an easy to administer questionnaire which focuses on the underlying motivational aspects that fuel players actions. These motivational aspects take the form of basic psychological needs: competence (the idea of challenge), autonomy (the desire for choice) and relatedness (connecting socially). The PENS is an easy to administer questionnaire which focuses on the underlying motivational aspects that fuel players actions. These motivational aspects take the form of basic psychological needs: competence (the idea of challenge), autonomy (the desire for choice) and relatedness (connecting socially). The PENS questionnaire was administered after each game was played, asking Likert style questions which relate to each of the above categories. The PENS was a viable tool in measuring enjoyment of each game, and the research had already shown that it would be more accurate in determining engagement and retention when compared to simple questions that related to enjoyment (which was previously used in study one). Further detail is outlined regarding the PENs, whilst also comparing

other methods of assessing enjoyment in the next chapter. For this study, the questionnaire only consulted the competency aspects of the PENS as there was naturally a lack of choices due to the prototypes being small (so the score for autonomy was expected to be low); the same was true for sociality, although questions were asked regarding the additions of social aspects – whether they were desirable and would increase engagement.

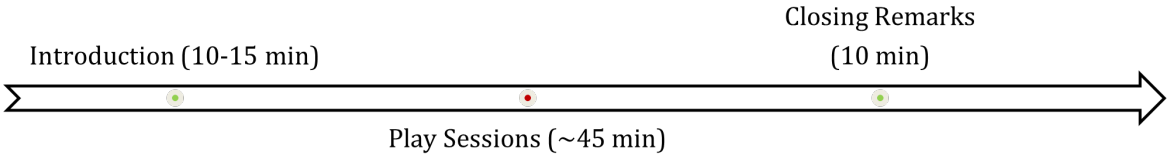


Fig. 5.15 Timeline of the study procedure

Please see the appendix for the specific questions that were asked during the study as well as key points of observation and the specifics of each mechanic and design choice posed.

5.4 Results

The comparisons of average competence, usability and educational Likert scores for each game is shown below in Figure 5.16. A one-way ANOVA was performed to compare each average Likert score of the five games. The ANOVA revealed that there was a statistically significant difference in mean score for each Likert score; (competence = $F(4,355) = [3.69]$, $p = 0.006$); (usability = $F(4,85) = [11.27]$, $p < 0.005$); (educational = $F(4,175) = [2.51]$, $p = 0.043$). A Bonferroni POST HOC test for multiple comparisons found that the mean value of the competency Likert scores was significantly different between Note Flash and Notes Invaders ($p=0.003$) as well as between Note Flash and Music Graveyard ($p=0.003$); there were also near significant differences between Note Flash and Staff Arcade, and Note Trainer when compared with Music Graveyard, Staff Arcade and Notes Invaders. Another Bonferroni POST HOC test for multiple comparisons found that the mean value of the usability Likert scores was significantly different between Note Trainer when compared with Note Flash ($p=0.009$), Staff Arcade ($p<0.005$) and Music Graveyard ($p<0.005$), whilst also finding that was a significant difference between Note Flash and Notes Invaders ($p<0.005$); finally finding a significant difference between Notes Invaders when compared with Staff Arcade ($p<0.005$) and Music Graveyard ($p<0.005$). A final Bonferroni test for multiple comparisons revealed that the Educational Likert scores was significantly different between Note Trainer and Note Flash ($p=0.002$), whilst also showing a near significant difference between Note Trainer and Music Graveyard as well as Note Flash and Staff Arcade.

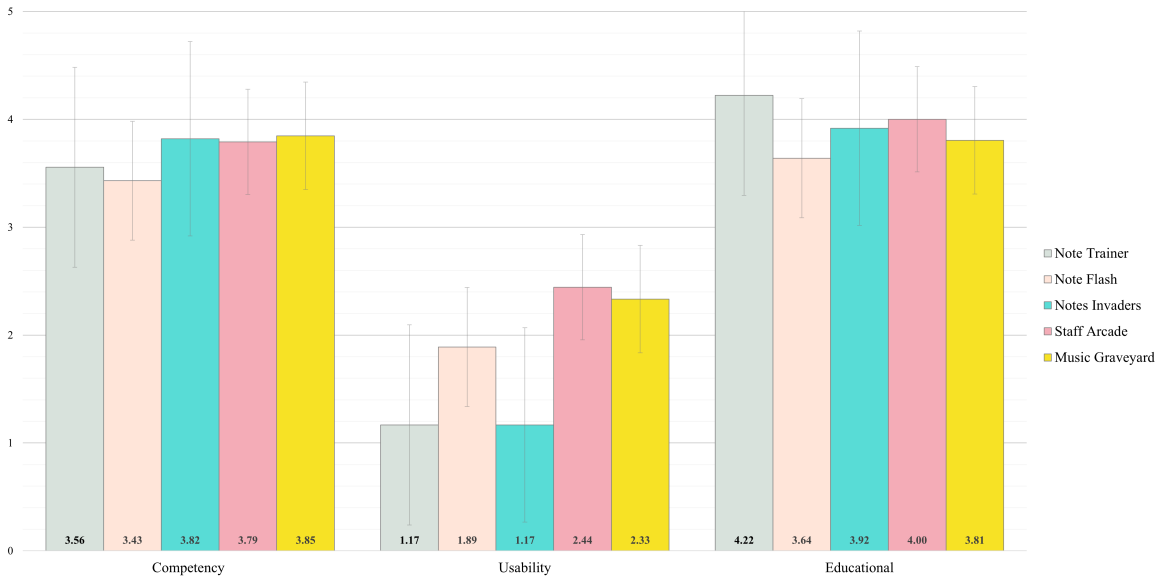


Fig. 5.16 Likert scores for each game in study two

5.4.1 Educational and Competency Likert Score Correlation

It was important to understand whether or not increasing the amount of gamification or if the practice solutions that were closer to the video game end of the spectrum would still yield educational value – and whether increasing the amount gamification or content regarding game design attributes would lower the educational value overall. Therefore, correlational tests between the Likert scores regarding competency and educational value conducted - which is visually represented in in Figure 5.20. A Pearson correlation coefficient was computed to assess the linear relationship between the Likert scores for each game. There was a medium positive correlation between the two scores for Notes Invaders, $r(70)=0.37$, $p=0.001$ and Staff Arcade, $r(70)=0.52$, $p<0.005$. Finally, there was a weak negative correlation between the two scores for Music Graveyard, $r(70)=-0.002$, $p<0.005$. For Note Trainer and Note Flash, there was no significant correlation found.

5.4.2 Qualitative Results

As part of the procedure involved conducting semi-structured interviews as well as asking the Likert style questions, transcripts of each interview were manually transcribed and a thematic analysis of the data was conducted. Through the analysis of each interview, the aim was to provide evidence to the deductions whilst also finding recurring themes relating specifically to each game and the experience of it, general changes which apply to all games and the overall study itself (regarding improving for next time). In order to

manage, organise and analyse the data, the management software system, *NVivo 12*, was used along with triangulation and a common seven step process (see appendix for details) to define overarching themes and consequent smaller sub themes. The 'parent themes' were 'Design' (any aesthetic related information), 'Mechanics' (relating to changes of gameplay or specific mechanics), 'Education' (any mention of the pedagogy for each game), 'Hardware' (any comments relating to the LUMI keys or the general study setup), 'Engagement' (any information regarding enjoyment, states of flow and continued use), and finally 'Usability' (referring to the onboarding, general ease of use and overall user experience). Further subthemes were defined relating to the above parent themes which helped gain insight into the why the above Likert scores were given by each participant.

A recurring theme related to the use of colour being distracting and that most participants stated it was a distraction rather than useful – opting to use the mode without colour. Other themes related to finding the balance of difficulty as most comments related to the games either being too difficult or too easy; the idea of increasing difficulty over time was received positively but could hinder the pedagogical value. A common design theme was the use of the on-screen keyboard, many participants claimed it was useful but wanted it to be larger and only show if it was needed - rather than being on screen all the time. Finally, it was clear that participants understood and found the pedagogical aspects of each game understandable and meaningful – specific themes related to the additional educational aspects of specific games (for example, the use of patterns and rhythm helping to build finger dexterity in Notes Invaders).The full thematic analysis is made available in the appendix.

General Mechanic and Design Choices

Using thematic analysis and reviewing answers to specific questions regarding the mechanic and design choices, overall choices and changes which could be applied to all games were found. These included:

- The preference of 'infinite mode' rather than 'level mode' as the main form of gameplay (whilst also ensuring there was a choice for both)
- Including juice wherever possible (choosing explosions over simple colour animations as well as adding further design to games which already had layers of design, for example, adding more refined artwork to Staff Arcade)
- Not forcing players to play to rhythm but encouraging them to do through additional 'juice' and score or rewards

- Overall, participants enjoyed all facets of every game and would prefer to see the implementation of all choices with the choice to decide which they prefer (which is what was expected due to the variation of player types and learner ability)

Specific Game Choices

Questions were also asked relating to specific mechanics on each game to try and understand what increases engagement and to gain insight into what each game should be focusing on, in regard to both design and mechanics. The choices per game included:

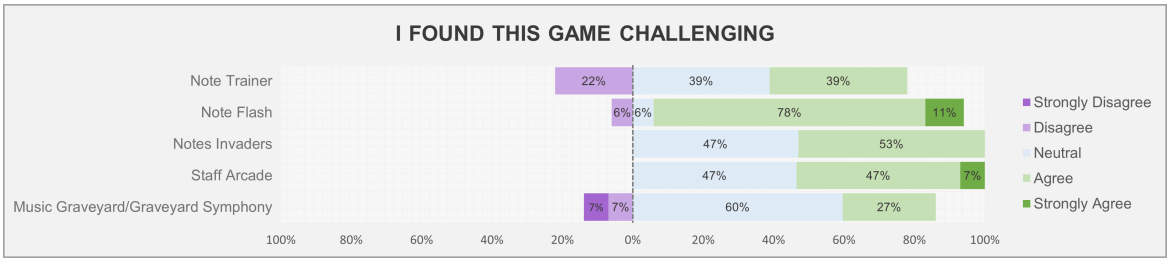
- Note Trainer and Note Flash both offered 'infinite mode', 'level mode' or 'survival mode' and the choice for 'survival mode' gained the most votes; participants preferred to challenge themselves in short bursts for practice
- In regard to the variations of Note Flash, most participants preferred the original version but also wanted to earn additional points for playing on rhythm (but did not want to be forced to, as the other variations required)
- For Notes Invaders, participants preferred a progression of increasing waves in which they could save their progress (breaking these waves into 'levels') as opposed to repeatedly trying to get further than their last attempts
- For all instances where 'adjacent mode' could be used in Staff Arcade, all participants preferred to not use this and would opt to use 'teleport mode' as it was easier and observations demonstrated it offered more enjoyability

5.4.3 Favourable Games

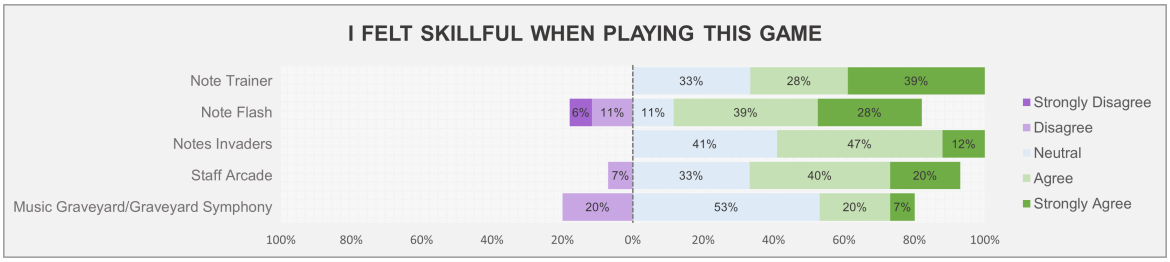
As with the previous study, and to determine which game would be taken forward in this research, questions were asked to which game was the most favourable of the session. Music Graveyard had an overwhelming response (with over half the participants voting for it), Staff Arcade came in second with four votes and both Note Trainer and Note Flash received at least one vote each. The observations of gameplay showed a similar reaction for each group, with Notes Invaders being an exception (which could be argued is due to the design). However, the reception of Music Graveyard was different from the rest. Participants showed signs of heightened interest and each one played over the ten minutes of play, asking if the game was available elsewhere to play test (where with all other games, participants typically played the set ten minutes or less – with the basic practice tools being played the least).

5.5 Discussion

The differences in competency between each game category were to be expected and this is overall positive. The results show that the Basic Practice Tool category (Note Trainer and Flash) was rated the lowest for competency and this is also reflected in the observational and interview data; most participants would complete the play session early and were not particularly animated when providing answers to each game (stating they had used similar tools). The lack of a significant difference between scores in regard to Notes Invaders, Staff Arcade and Music Graveyard is somewhat expected, especially because the highest rated game was Music Graveyard, the solution that resembled a video game most closely. However, it is believed that ratings may have been higher and the difference potentially significant between all games and Music Graveyard if the questions posed were fully understood and Music Graveyard was designed to be more challenging. Whilst participants rated 'satisfaction' and the likelihood to return or recommend Music Graveyard the highest, they rated the idea of challenge and the application of a particular skill low (all four criteria were used to generate the score of competency). The games' learning content was purposely designed to be simple as it believed that the concept was already somewhat complex and did not want to overwhelm participants. In reality, all participants understood the concept with ease and as such were not challenged enough which also meant they were not applying their musical skills in an in-depth manner – leading to a lower competency score.



(a) Stacked bar charts showing lower scores for Music Graveyard regarding Challenge scores



(b) Stacked bar charts showing lower scores for Music Graveyard regarding Skill scores

Fig. 5.17 Stacked bar charts of Skill and Challenge scores for all games

The difference between usability for Note Trainer and Note Flash was also expected. Note Trainer was very basic and did not offer additional variations, whereas Note Flash also included the rhythm variations. These variations led to confusion amongst some participants and led to lower scores for ease of use. This also applies to all other games and the greater differences in usability score as the solutions became more gamified, was expected; the interview and observational data helped us implemented more robust tutorials and simpler UI to ensure that each game's concept was easier to grasp and the user experience was more intuitive. An unexpected result was the difference of educational score between Note Trainer and Note Flash (as the expectation was for them to be similar) but this also reflects the variations of Note Flash being complex and leading to lower educational scores. The differences between the Arcade category and Basic Training Tool category, was somewhat expected as the comments received were that Staff Arcade was an enjoyable game but the various mini games felt more game-like and less pedagogical (as well as being too complex to be a meaningful practice tool). The difference in educational score between the basic trainers and the training game was expected but it is believed this difference would have been less so if the educational content of Music Graveyard increased (as stipulated above, this was not the case reduce complexity of the game).

The lack of correlation between competency and educational score for both Note Trainer and Note Flash was not surprising as they were designed with a lack of gamification and for the purpose of practice. The positive correlation that was found in Notes Invaders and Staff Arcade was interesting as it points to the conclusion that adding more gamification would actually increase educational value. This result indicates mostly that increasing challenge and required skill, would lead to higher amounts of educational value as the more skill required, the more meaningful and applicable practice would be; this would naturally lead to higher amounts of challenge. The very weak negative correlation observed in Music Graveyard, combined with the low usability score, indicates that the game was not robust enough in regard to onboarding and consistent tutorials which must be paid attention to; the higher amounts of gamification or elements of game design needs to be coupled with attention to detail regarding instructing learners on how to play and understand the game at every stage.

5.5.1 Study Limitations

Whilst the study had improved upon previous limitations of the initial study by focusing on a specific area of skill (reading notation), focusing on specific mechanics or design choices, using peer reviewed methods of assessment regarding engagement, not limiting the play time per session and improving overall observational and interview techniques, some important

aspects were still neglected and would need to ensure they were improved for future studies. These limitations include:

- The reliability and validity of the testing methodology was not considered. Although the assessment of engagement was based on prior literature, it is deemed a limitation that this and the other methods of assessment were not validated nor was their reliability taken into account
- Whilst PENS was used for assessing engagement, the implementation was limited. The full PENS was not taken into account (only considering competency and overlooking both relatedness and autonomy). Whilst this was intentional, it was found that these questions would have been useful and not added any more complexity to the study
- Although PENS was used, albeit in a limited capacity, other methods of assessing notions of engagement or enjoyability were not reviewed - this was mostly measured using observations which lacked standardisation
- The study still used open ended and subjective measures of educational value for all games whilst also not considering how each game improves the specific skill of reading musical notation
- The study was lab-based and did not reflect real world applications; whilst it offered a lot of control, this methodology can never be a true representation of real-world practice or learning
- The study had also measured usability with personal forms of measurement but neglected to consider other methodologies found in literature or the market place

5.5.2 Future Implications

One of the main outcomes of this study was to choose specific mechanics and designs whilst also narrowing down the developed prototype games to one or two concepts. All the data indicates that the game which was received most positively was Music Graveyard, which was expected. Going forward, this game was developed further, taking on board feedback regarding onboarding, simpler controls and coherent, consistent tutorials throughout (which should lead to a more pedagogically valuable concept). The choice boiled down to combining aspects of Notes Invaders and Staff Arcade into one sole game or going ahead with Music Graveyard. Whilst ideally both would have been taken forward, there was limitations of both resources and time. What finalised the decision on Music Graveyard was the observations

and overall feedback. As mentioned, participants were incredibly animated when playing the game and found it incredibly novel (a theme amongst participants of all age groups and skill levels). The final goal was to test the game in real world applications, improve assessments of engagement and usability by reviewing literature, and begin to determine how one can measure the improvement of the skill of reading musical notation in an objective and standardised manner – determining the application this would have in the real world.

Going forward, Music Graveyard was improved based on the feedback, ensuring that the hardware is not restricted to the LUMI keys and a review of literature is conducted, giving way to more robust methods of assessing engagement, usability and pedagogical value (specifically measuring the improvement of a specific skill and its application). How this can be reflected in real world scenarios is consulted by running a pilot study which is used as a basis for a longitudinal study conducted remotely in learners homes. The goal was to determine how effective this novel method of practice can be for beginner adult keyboard learners and whether or not this would eventually lead to longevity of learning or reduce the high rates of early drop out exhibited by these learners.

5.6 Chapter Conclusion

This chapter discusses the second round of development which begun to focus on games which have a specific purpose: improving a beginners ability to read musical notation. The categorisation of each game into specific groups help determine how gamified each practice game could be and defined considerations to what is required to be implemented to ensure that pedagogical is maintained whilst the amount of game design attributes are increased. Through a second study, it was realised that the most game-like solution could be used if particular attention is paid to onboarding and tutorials which should ensure that the main game, Music Graveyard, can be deemed a viable learning tool when compared to typical practice methods. However, there were some major limitations of the study, notably this was lack of validity and reliability whilst also neglecting to measure usability and engagement in a robust manner. In the next chapter, the development of Music Graveyard is discussed and it's use it in a pilot study which is used as a basis for the final longitudinal study. The pilot study helps to remedy the limitations of the second study and bring together the missing pieces; helping to ensure that the game has real world application and meaningful transferability to learning and playing keyboard.

Chapter 6

Note Reader Adventure: A Learning-Based Game

6.1 Chapter Introduction

Thus far, it was realised that there was a need for specificity and standardisation to conclusively state that these novels games would be useful in increasing practice rates; which would build positive associations between learning and practice - eventually leading to less beginners dropping out quickly from their studies. Towards this, several prototype games which were centred around the ability to read musical notation, specifically, matching positions on a musical staff to physical keys on a keyboard were developed. Through the previous study the conclusions was that the most gamified approach to practising reading musical notation was ideal to take further and build methods of assessment which would show that this approach to practice would yield higher rates of engagement, thus leading to increased longevity of practice, and consequently, the entire learning journey. However, key limitations of the previous study highlighted the need for a standardised method to assess pedagogical value, which would require reviewing relevant literature to offer a valid method of assessment. The study also neglected many aspects of assessment regarding the assessment of engagement (or enjoyment) whilst also not offering comparison methods which would help define a distinct methodology to this regard. Finally, a method of tying tie all of these limitations and applying them to real world scenarios was required as this is an aspect that is commonly overlooked in this area of research (offering solutions which had meaningful transferability and real-world applications).

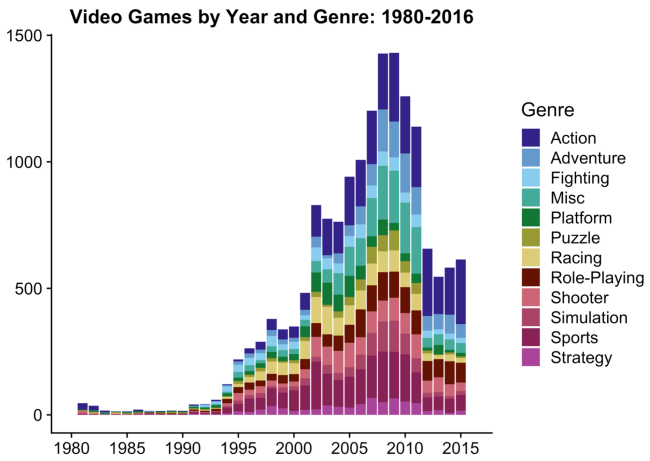
At this stage, the next objective was almost a full circle of the initial goal that was originally set. The original goal was to have a suite of games in which longitudinal studies

would be run to determine their effectiveness compared to typical methods of practice (i.e., would video game approaches to practice be more effective at yielding higher rates of practice). For this stage of the research, this single objective was applied to a single concept, in which further prototypes could be built with the goal to test groups of games in a single instance. It was important to ensure the validity of such a study (and method of assessment) before developing such a large-scale cycle of development and testing, to help avoid investing a large amount of time and resources to a process which was flawed from the start. Therefore, the latest prototype game would be used in a pilot study with similar goals on a smaller scale – building a method of assessment which could be applied on a much larger scale. The goals of this pilot study were to ensure validity of assessing engagement, usability and pedagogical value within real world settings. The study needed a way to determine the pedagogical value of the game; specifically, a way to determine whether the game could improve the skill of reading musical notation using highly reliable and valid quantitative methods. Essentially, the underlying hypothesis was that the more a learner engages with practice, the more they will improve the skill. Whilst it was a rather logical conclusion that video game practices would yield higher amounts of engagement; it was not clear whether or not the developed game had the ability to improve the skill of reading musical notation.

The pilot study would be a much smaller scale instance of the final longitudinal study which would help validate the methods of engagement, usability and pedagogical value; improving upon the key limitations found for larger scale studies. This chapter outlines the developments made to the game, based on insights gained from before and new literature before discussing the pilot study. Key findings of the study are explored relating to how engaging and usable the game was, whilst also discussing how one can improve upon these methodologies for future studies. Finally, how effective the developed prototype game was in regard to improving the skill of reading musical notation, when compared to a typical practice tool, is investigated. The results showed that the game was just as effective in improving the skill of reading music whilst also being more engaging in comparison to the training tool. The game was easy to use and, when compared to the training tool, most participants rated the training tool higher than in regard to overall usability. The feedback regarding the design and specific mechanics of the game, is outlined in the qualitative results gained from the interview portion of the study, which are then applied to a final iteration of the game. The final study was longitudinal in nature and used the premise of the pilot study as a foundation, building upon the main limitations found at this stage.

6.2 Note Reader Adventure

The second round of development began for the RPG style game, currently titled 'Music Graveyard'. The title was still a work in progress for this round of development and assessment, therefore the game was titled to be as descriptive as possible, resulting in: 'Note Reader Adventure. Specifically, the games' genre was defined as rhythm adventure RPG with some parts of a roguelike instilled. Essentially, the game had adventure elements (exploring, narrative and placing the main character as the hero) as well as RPG elements (levelling systems, currency collection and shops) with aspects of roguelikes (dungeon crawling and a typical fantasy design). As mentioned, the choice for this style of game allowed a lot of content and complexity to be added without the over designing the graphical elements or intricate mechanics. Not only this, but these genres are particularly popular at the current time of writing and are familiar to the majority gamers and non-gamers alike; the game would be recognised as a game without needing to stipulate how it is played or what the common drivers and core loops are. As previously argued, there was a desire to develop an arcade style game but this would require hand creating all levels which would lead to a lot of debugging and tweaking to find the balance of each level; with a game that borrows from roguelikes, one could procedurally generate content which allows time to be focused on the elements which matter most. Finally, whilst development of such a game would require a lot of time, the foundation of the game had already been created and developing additional content would be less demanding than starting completely from scratch.



Popular Game Genres Over The Years]Bar chart highlighting total number of games developed per year from 1980-2015

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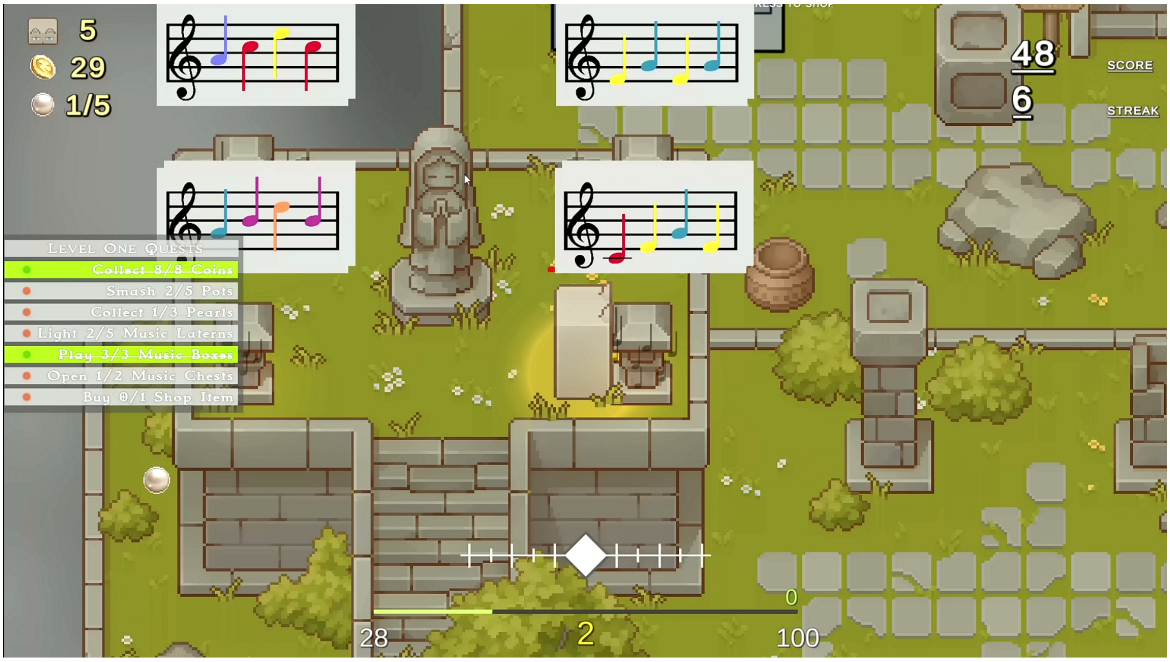
6.2.1 Insights From Previous Study

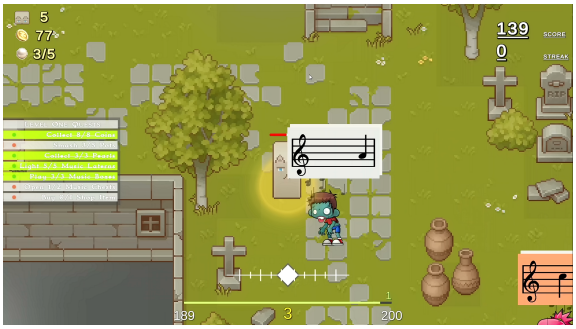
Many of the insights and lessons learned from the previous study were considered in the further development of the RPG style game. The preference of playing games in an 'infinite' capacity as opposed to levelling resulted in additional developments to the arena mode whilst later creating multiple levels using procedurally generated content (this also was based on the feedback that users wanted as much choice as possible). The game would offer additional points for rhythm but players could choose whether they wanted to be 'forced' to play to rhythm (as feedback showed this was too demanding for beginner learners or novice gamers). Where possible, additional 'juice' (Hicks et al., 2019) was added in the form of visual effects (VFX) and rich sound effects (SFX) – all sounds would revolve around a common theme and relate to specific keys to help build audiation skills. Notation shown would either be single notation which was easy to read or make use of patterns that would add musical depth and help to increase specific techniques with the fingers. Finally, the on-screen keyboard was still provided but it was hidden behind a menu, which allowed players to show it all the time or refer to it when additional help was required.

6.2.2 Game Description and Pedagogical Nature

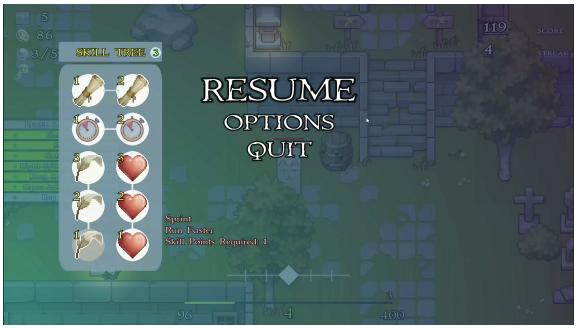
Previously, a multitude of games were used as inspirations for the development of this game. During this stage of development there was a particular focus on a few specific games in which mechanics and design choices were borrowed and modified to fit within this games scope. Specifically, *Crypt of the Necrodancer* (and the adventure style DLC game, *Cadence of Hyrule* were reviewed continuously throughout development and specific mechanics were borrowed such as, health and lives systems, collection of coins and the ability to purchase powerups and the main aspects of how rhythm was used, including the visual design of the tempo on screen. Another game that was used heavily was, *Epistory - Typing Chronicles* as the game had a unique control system designed to improve touch typing skills at a typing keyboard. Ideas such as the quest system and levelling up the character were inspired by this game and the design was consulted throughout further development of the RPG game. Finally, whilst the design and general gameplay was rather different, *The Touryst* provided some inspiration for this game. It's simple but satisfying quest line and in game puzzles helped to add more depth to the RPG game and ensure that the narrative was related to the design of the game and made players feel like the hero of their own stories. The general concept of the game and the overarching core drivers and loops have previously been discussed, what follows below is a description of how the game is played and a more in-depth description of the specific game elements.



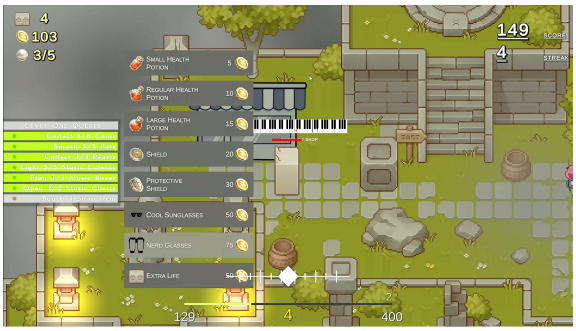
(a) Screenshot of Note Reader Adventure with notation being shown



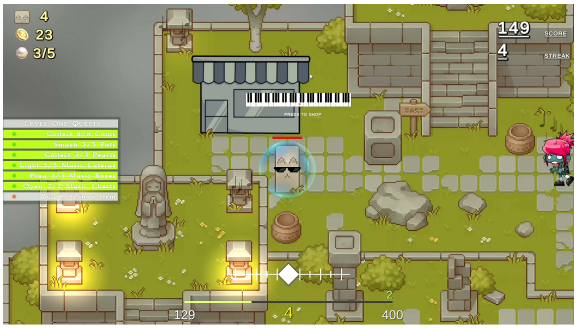
(b) Note Reader Adventure zombie enemy



(c) Note Reader Adventure skill menu



(d) Note Reader Adventure in game shop



(e) Example of Note Reader Adventure purchased cosmetic: sunglasses

Fig. 6.1 Note Reader Adventure Screenshots

Players control the main character using a MIDI keyboard with a total of 48 keys: the lower side of the keyboard is used to control the character movement and the higher side of the keyboard is used to carry out certain actions, such as switching from play mode (in which players can see notation) to move mode (in which the keyboard is used to move the character and interact with the world, a crucial part of the game). The control scheme encourages players to place their fingers on the keys in certain ways, which reflects typical early-stage hand positions found within teaching (for example, the five-finger position (Furuya et al., 2011)). For the most part, players must complete each level by playing all the notation found (in which patterns of notes are used to improve finger and hand dexterity, implementing basic finger exercises found in typical learning), though more depth is added to the game to ensure that it was not just a typical trainer with a different guise. So, not only are players required to play the musical notation, but they must solve simple puzzles, navigate through tricky mazes, defeat enemies in unique ways, collect additional items and coins which can be spent in shops in order to improve the character's abilities and style (i.e. powerups and cosmetic items). Whilst most of these additional game design concepts integrate with the learning, for example the puzzle elements focus on placing notes in a correct ascending order, it was intentional that certain game design concepts to be a distraction from the learning to help ensure that players felt like they were playing a traditional video game, rather than a practice tool. The notation that players are required read varies over the course of the game, starting with the basic notes and eventually adding more notes to the gameplay; learning books (Palmer et al., 2005) and applications were consulted to build a unique progression of reading notation, focusing on landmark notes and building from this. Notation is viewed either as single notation cues (i.e., one note on either treble or bass clef) or as a pattern (typically made up of 2 double notes or 4 quarter notes); some objects require multiple patterns in which notational cues are 'stacked' atop one another – once the player reads the first pattern the second one is revealed.

As this is a game centred around music, it was imperative that music and rhythm were a core element of both the design and the mechanics of the game. Using paradigms observed in existing music games, rhythm was implemented in many aspects of the game in order to encourage the player to hit the notes on the beat, which offers a greater feeling of satisfaction and improves their rhythmic ability (another fundamental skill). The game features a visual and audio metronome accompanied by a backing track which has a clear tempo, whilst also flashing other elements to the beat, for example a 'dance floor' the enemies move in time to the beat and most of the animations are timed to the beat of the music. Finally, if players move or interact in any way to the beat, they build up a streak. The higher the streak, the higher score multiplier they receive but they will lose the streak if they miss a beat (building

on the gamification concept of 'sunk cost prison'). Because this was an RPG style game, it an important aspect was level progression with unlockable skills. Players gain experience points (XP) by completing any positive action (playing notation, completing a puzzle etc.) and on levelling up, they can spend their skill points on specific abilities which help render the game more enjoyable and eventually easier; abilities include slowing down enemies if they play the correct note of the corresponding enemy notation, gaining extra health and not losing multipliers quite as easily.

6.3 The Pilot Study

This pilot study was used to ensure that the various assessment methods were validated and were measuring what was intended, ensuring that the game could be played without any intervention or game-breaking bugs and that the game would offer equal pedagogical value to a typical form of reading musical notation practice. Specifically, a pre and post-test with intervention experiment approach was adopted (i.e. a pre-skill test, an intervention which is either a practice game or tool, followed by a post-test in which pre-to-post test scores were compared to). The study explored how each solution was perceived by participants in regard to educational value, usability and engagement through Likert style questions and observations; the aim was to find that the game group rated, at least, the engaging component higher than the practice tool. Below is details of the study protocol in which the specific methods that were conducted to measure the aspects of engagement, usability and pedagogical value (i.e., the ability to improve the skill of reading musical notation) are discussed. The following outcomes of the study are as follows:

- Ensure the methods of assessment regarding engagement and usability are valid, reliable and measure what they intend to
- Validate the method of assessing the games' ability to improve the skill of reading musical notation, in comparison to a typical method of practice; ensure that the game does improve the skill of reading musical notation just as well if not more so than the comparison practice tool
- Ensure the prototype game can be played without intervention outside of lab-based environments
- Ensure the prototype game has no major bugs or areas of confusion (i.e., ensure that it can be played without issue outside of lab-based environments)

Regarding the 'experimental phase' of the study, i.e., the comparison of skill acquisition and application regarding the prototype game and typical practice tool, the expected hypotheses are stated:

- The null hypothesis (N0) is that the developed prototype game will not improve the skill of reading musical notation or that it did not improve the skill to the same standard as the practice tool
- The alternative hypothesis (HA) is that the developed prototype game will improve the skill of reading musical notation to the same standard, or in fact greater, than the practice tool

6.3.1 Participants

The sample consisted of 18 participants (6 females) aged 18-64 in which an equal variance of age groups was observed (besides from the age group of 55-64, where there were only 2 participants). The majority of the participants were amateur musicians who lacked any experience reading musical notation besides from two participants who had at least 5 years' experience playing the keyboard and were competent in reading music. There were only 2 participants who did not play games on a regular basis whilst the majority of participants played either at least an hour or two a day or whenever they could within a period of a week.

Table 6.1 Pilot Study Participant Demographics

	Age Group			
Demographic Information	18-24	25-34	35-44	55-64
N (Count)	6 (34%)	5 (27%)	5 (27%)	2 (12%)
Gender (count)	4M (66%)	3M (60%)	4M (80%)	1M (50%)
Experience Reading Music (out of ten; mean)	2.2	2	3.8	2.5
Gaming Habits mean)	1-2 Hours Per Day	2-3 Times Per Week	2-3 Times Per Week	Once a Week

Whilst the aim was to recruit mostly amateur musicians who played video games regularly, it was important to capture a varied audience to ensure that the usability of the developed prototype game was understood by a wide range of learners outside of controlled environments whilst the varied experience of learners would help to validate each skill test.

6.3.2 Protocol

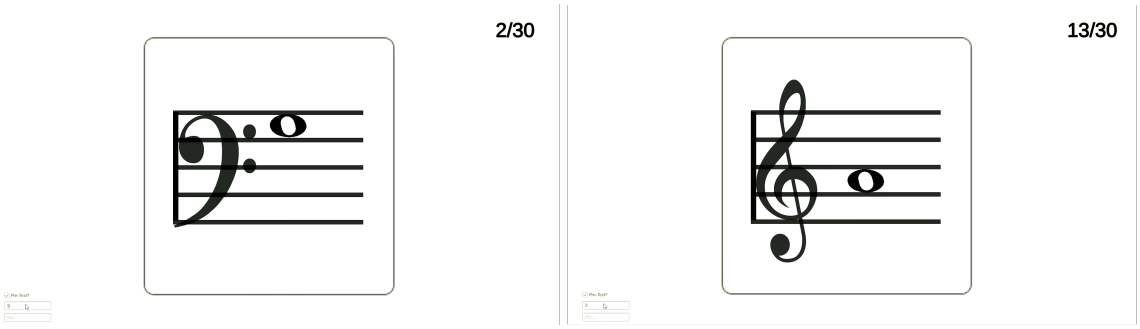
Mailing lists from the previous study as well as students in both the music and games technology courses at Bournemouth University were contacted via email for recruitment. A £20 Amazon voucher was offered as an incentive to increase the likelihood of recruitment.

The participants from previous studies (i.e., those from ROLI mailing lists) were ideal for this study, however, extending recruitment to game and music students at Bournemouth University would help to increase the size of the sample and to ensure that the sample reflected the target population - independent casual learners with an interest in video games (in which, students from music and games courses were ideal). The study was conducted in both the company's headquarters office as well as on campus at Bournemouth University. Demographic information was gained by asking participants to fill out a small survey to show their interest in participating and this helped determine whether the participant would fit the intended demographic before conducting the study with them. A small introduction phase during the study that was useful in reiterating this information and gaining more detail about each participant.

After the introduction phase of the study, participants were administered two tests to measure their ability of reading musical notation. The two tests were intended to measure the acquisition of the skill of reading musical notation and the application of the skill in a real-world scenario. Whilst studies found in literature would prove that participants would improve on specific tests, for example, the improvement of recalling specific notation or patterns (Rogers et al., 2014), there was seldom any mention of what real world application this may have for a learner. Therefore, the goal was to ensure that the game would help to acquire the skill of reading music in comparison to a typical practice method, whilst also determining how this would impact real world applications outside of this study.

The first test was to gauge the acquisition of the skill (i.e. their ability to match positions on a musical staff to physical keys on a keyboard). The initial test was derived from Wong et al. visual fluency task with musical notation. The visual fluency task focuses on a particular aspect of visual object recognition - the ability to individuate visually similar objects (music sequences in this case), or to perform subordinate level categorization (Logothetis and Sheinberg, 1996). It uses a sequential matching paradigm to measure how fast one can recognize a sequence of musical notation, and a similar task has been used to measure the visual perceptual fluency of recognizing English words and Chinese characters (Wong et al., 2019). Participants first see a target sequence, which is presented briefly on the screen and then disappears. Then, they see two sequences on the screen side-by-side, among which one is identical to the target they just saw, while the other is a highly similar distractor. Their task is to select the identical target among the two options without any time limit. There were limitations with this task in regard to measuring the acquisition of reading musical notation skills. Firstly, the test could be considered a measure of one's ability to simply remember certain visuals and recall them in comparison to distractors or to simply determine the differences between subjects. The test also did not measure the relationship between

physical keys and visual positions on a musical staff (the skill this study was seeking to measure). Finally, as third parties developed the test, there was no way of controlling the content nor ensuring standardisation of the tests – whilst it would be objective, relying on third party implementations could have led to inconsistent data. The outcome of these limitations resulted in the development of a custom designed recall test, somewhat based on the concept of Wong's work, which would have a simpler and more specific form of assessment: a novel flash card test conducted using a MIDI keyboard. The test focuses on a learner's ability to match a notation given on either treble or bass clefs to a physical key. A random notational flash card is shown (using basic single notes within a given range) and participants are allowed as much time as they need to play the corresponding key. Score is based on two factors: recall accuracy (how many errors are made before the correct key is played), and recall time (how long it takes to correctly guess and total time to complete the test itself – the sum of time taken per question).

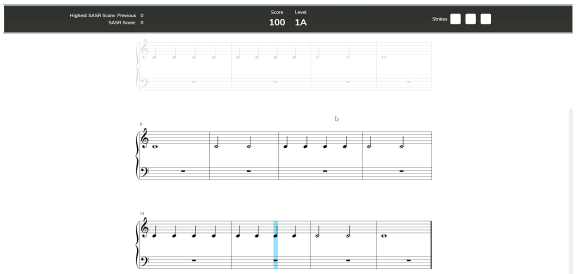


(a) Flash Card test showing bass note cue (b) Flash Card test showing treble note cue

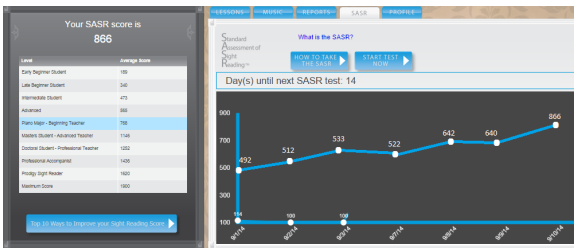
Fig. 6.2 Flash Card Example

For the application of skill, it was important to try and reflect what the most common application would be for reading musical notation. Not only this, but the game also utilised other fundamental skills as secondary mechanics which included rhythm, audiation (using sounds to solve simple puzzles) and executive functions (playing notational patterns to improve basic hand and finger dexterity) so it was important to see what impact this would have in regard to their application. This application of skill would therefore be playing a piece of basic sheet music (the most common desire of casual beginner keyboardists). Reading a piece of music which one is not familiar with for the first time is also known as sight-reading. Whilst this research is particularly concerned with the ability to read music over a given period of time, due to lab-based settings along with time and resource constraints (a lack of budget) it was not feasible to ask participants to attend practice sessions on a regular basis over a given period and learn a single piece of music. Therefore, the test would be more related to sight-reading, which would still give an approximation of a learners ability to

read music and play it in time with correct form. Typically, to determine a leaners ability to sight read an experienced teacher is required. Whilst this method is sound and can be relied upon through interrater reliability, the number of resources required to do so adds up and the fact still remains – one relies on a qualitative measurement which lacks replication. Rather than this approach, the study adopted to use 'Standard Assessment of Sight Reading' (SASR). This method is an extension tool of Piano Marvel (*Piano Sight Reading Test (SASR) | Piano Marvel*, 2018) and bases a participant's score on typical measurements of sight reading: accuracy, tempo stability and rhythm recall. The benefit of this method is that it is measured by a computer and therefore there is no room for human error. Participants get 20 seconds to familiarise themselves with a monophonic motif (a basic sight-reading exercise) before being counted in to play it. A metronome can be used at this stage as well as a basic backing track to help participants keep in time. A total of three exercises were used and the average of the score (their 'SASR score' will be used to determine their ability to sight read). Participants who performed poorly (the measurement of performance was based on the accuracy of notes played and rhythm) were shown an easier follow-up piece, and vice versa, to help accommodate for variation in skill.



(a) Example of exercise one from SASR test



(b) SASR score and progression card

Fig. 6.3 SASR Test Example

Once a participant had completed both skill tests, they would be placed at random into one of two groups where they were required to practice for a total of 15 minutes using either the prototype practice game or the online practice tool (a popular and standard tool of practice for reading musical notation, see below for further details). In the previous study, the time limit for practice was flexible, however in this study participants were required to practice for a specific amount of time in order to ensure standardisation across both groups (i.e., to maintain consistency and fairness). The choice of fifteen minutes was based on similar tests found in the literature (Wong et al., 2021) but it was also deemed the longest amount of time a participant would be willing to practice with such tools for the first time (using previous studies as a benchmark). Each group's intervention method had the same

'educational content', i.e. each group was shown the same set of notes to practice but in vastly different formats. They were instructed on how to use the tool and the basic premise of the game but could use the time as they wanted to and were only assisted if they requested (this would also help to ensure the usability of both solutions for future studies). Once the intervention period was completed, participants were administered the same tests as the pre-tests in which comparisons would be made.

Finally, participants were asked a set of Likert-style questions (out of 5) in order to gauge their opinions regarding educational value, usability and engagement of either solution. Educational potential was measured in a relatively simple manner with 1 or 2 questions, following the same structure as the previous study. Whilst the skill tests would be an objective form of assessing skill acquisition and improvement, the Likert style questions would also lead to further insights into what specific aspects of each solution would be most useful for practice from each participants response; it was also useful for comparisons of previous studies (i.e., to ensure that the changes made had a positive effect). Usability was measured in a similar way as before, with more specific questions derived from literature (Inchamnan and Wyeth, 2013) and using the knowledge gained from the previous study to highlight important areas of observation (how participants would use menus, place their hands on the keyboard and the time it would take to find flow (Jackson, 2014) in practice).

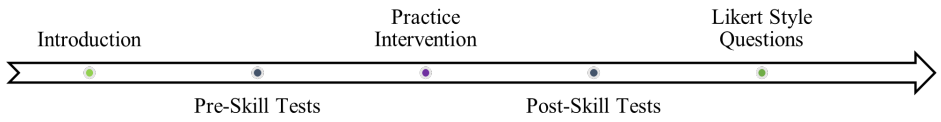


Fig. 6.4 Timeline of the pilot study protocol

Limitations of the previous study highlighted the partial implementation of the PENS for assessing the engagement of the prototype games whilst also not reviewing the literature for other more appropriate methods of assessing engagement. For this study, these limitations were rectified and all factors of the PENS were considered. The only motivational element that was not considered for the PENS was relatedness (social impact). This was intentional as neither the game nor the comparison practice tool made use of any social elements so asking questions in this regard would be redundant and only lead to confusion. Whilst the PENS was a viable assessment of engagement which considered key motivations in consideration of challenge, choice perception and sociality, it was not entirely comprehensive enough to capture the individual differences of players across various types of games. Therefore, a review of other assessment methods that seek to measure engagement and challenge was conducted. Regarding challenge as a player experience, Denisova et al. sought to create a specific questionnaire which considered specific factors that influence a players experience

of challenge and what experiences may emerge from a player being challenged. These factors include Difficulty and Skill, Learning and Mastery, Flow and Immersion, Uncertainty, Enjoyment, Competence, Suspense or Curiosity and Success and Failure. This work also reviewed 9 widely used questionnaires and summarised their related items in which they found recurring issues of lack of depth and, as mentioned previously, not being comprehensive or applicable to the vastly varied types of games that are developed. Whilst this study made use of the PENS for categorisation of the various motivations that comprise engagement, specific questions were defined based on the findings of Denisova et al. research as well as consulting the Game Experience Questionnaire (GEQ) (Poels, 2007), another popular questionnaire used to measure a player's experience and to predict various motivators of a game. These specific questions were placed in the categories of competence or autonomy. Competence was defined as the optimal challenge a player may feel (Deci and Ryan, 2000); and autonomy was defined as the amount of freedom and choice the player perceived they had.

The Comparison Practice Tool

A third-party practice tool was used (*Sight Reading Trainer*, 2016) for comparison in order to avoid bias. The tool consists of a staff (which participants can choose from treble, alto, bass or grand) and a series of notes which can be chosen by the user are displayed (the notes which are spawned based on the users' choice follow no melodic pattern and are a purely random series). The one action users can carry out is playing the first note seen on the staff (the note they play can be visualized on the staff to help orient themselves if they are unfamiliar with the note they have to play) and three scores are collected: total correct, total incorrect and the current streak (i.e. how many they have got correct in a row).

The tool has no elements of gamification or features of game design beside the score. This simple but effective practice tool was ideal as it would make for fair and logical comparisons. In contrast to the game, there is a lack of musicality in that there is no background music nor rhythmic aspects, the user interface is somewhat convoluted and there is a lack of guidance, but most importantly, the key difference is the lack of game design and gamification.

6.4 Results

The data was broken into two areas: quantitative and opinion based (i.e., qualitative). The quantitative data is made up of the results from both skills test in which comparisons are made between and within groups. The opinion-based data is summarised by the Likert data, where comparisons between groups are made, as well as any observational data and feedback

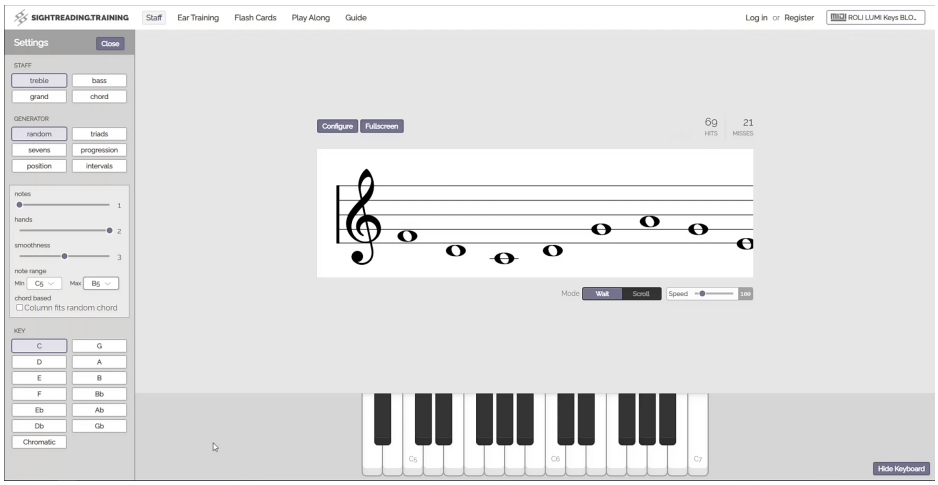


Fig. 6.5 Screenshot of the practice tool

given by the participants relating to specific reasoning for scores. Below is a summary of the data as well as a discussion of the reliability and validity of the evaluation criteria (the tests) and the comparison criteria applications (the methods of practice).

6.4.1 Flash Card Results

Wilcoxon Signed Rank tests showed that there was a significant difference from pre to post scores (p = 0.0002) within both groups and the effect size (using Mann-Whitney tests) observed was large (0.58), implying that both groups had improved from pre to post and that this would also be the case in a larger scale study. There was no significant difference between each group's performance and, thus, the null hypothesis could be rejected based on recall time alone.

Wilcoxon Signed Rank tests demonstrated that there was a significant difference from pre to post scores (p= 0.002) within both groups and that the effect size observed was moderate (0.57), implying that both groups had improved from pre to post and that this would be the case on a larger scale too. Whilst there was no major significant difference between each groups performance (p=0.06), the difference found was near significance and, when looking at the data closely, it was apparent that the game group had improved more so than the tool group. Based on these findings, it is safe to reject the null hypothesis on the recall accuracy criteria alone.

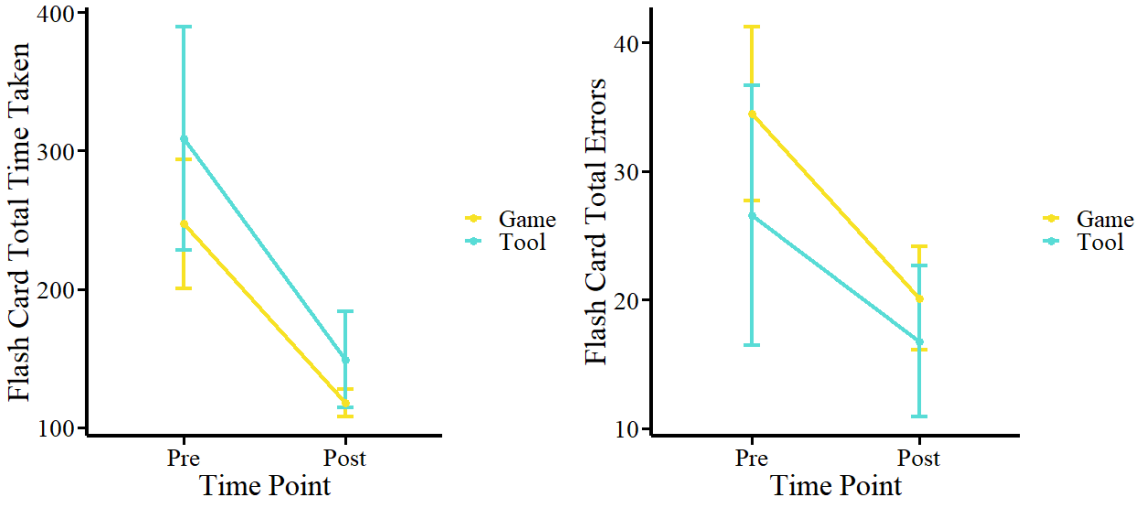
	Pre		Post	
	Game	Tool	Game	Tool
Count	9	9	9	9
Mean	8.23	10.3	3.93	4.97
SD	4.65	8.06	0.99	3.46
Median	5.7	6.8	3.77	4.22

(a) Study Two Recall Time Scores

	Pre		Post	
	Game	Tool	Game	Tool
Count	9	9	9	9
Mean	34.4	26.6	20.21	17.6
SD	20.3	30.2	12	17.6
Median	30	30.2	17	8

(b) Study Two Recall Accuracy Scores

Table 6.2 Recall Time and Accuracy scores from pre to post for both groups



(a) Line plot of the recall time from pre to post for both groups

(b) Line plot of the recall accuracy from pre to post for both groups

Fig. 6.6 Recall time and accuracy from pre to post for both groups

As the flash card tests showed participants random questions and each participant was shown a variation of different questions, there was no apparent discernible way to infer that the results observed were not due to the questions they received. Therefore, occurrences of questions were observed and statistical tests were performed to determine whether there was any significant difference of questions occurring between and within each group. There was no significant difference observed and, therefore, any conclusions that may be reached regarding the data from the flash card tests can be replicated.

6.4.2 SASR Results

SASR scores were compared using two criteria, first the overall score generated by the algorithm and also the individual scores for each exercise. It was important to compare the

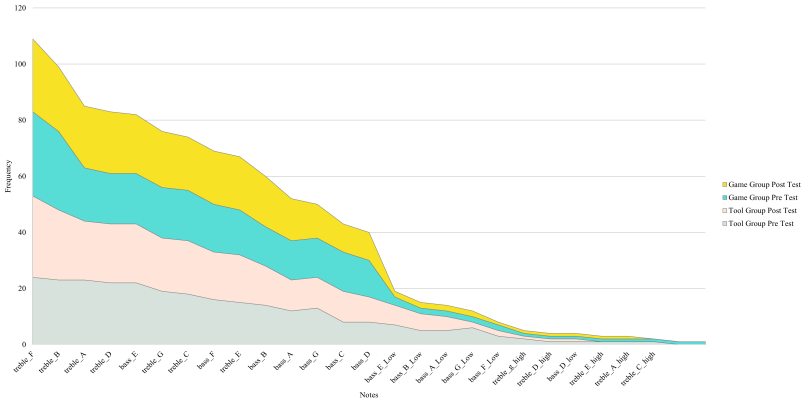
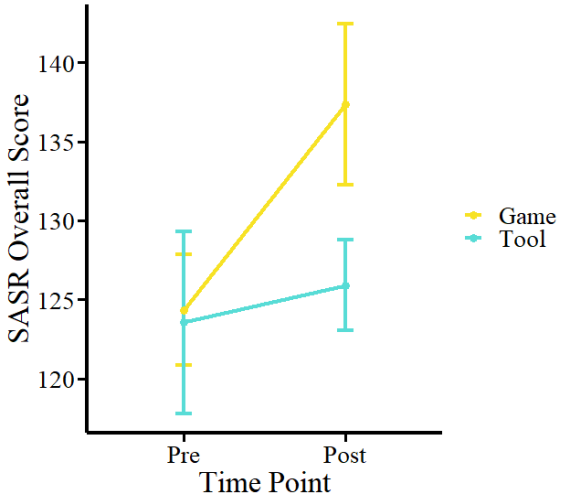


Fig. 6.7 Occurrences of questions posed during the flash card test

individual exercises in order to ensure that the score generated by the algorithm was correct and that the data was as transparent as possible. Standard t-tests were used for the overall SASR scores where there was a significant difference in pre to post scores (p= 0.042), with an effect size recorded of moderate (0.549) and no significant difference observed between groups. However, using a Wilcox Signed Rank test for the difference in scores from pre to post, there was a significant difference between groups (p= 0.032) and that the effect size observed was moderate (0.360). Looking closely at the data, it was inferred that the game group had improved more than the practice tool group.

The same analytical procedure was applied to each SASR exercise and compared the data within and between groups. The results implied that there was only a significant difference from pre to post scores regarding exercise 1 within both groups and that the other exercises exhibited no difference in pre to post scores. When comparing the scores between groups, there were no significant differences between each group on any exercises, nor was there any significant difference in the change of scores from pre to post for each exercise.

As with the flash card tests, each SASR exercise the participant received was random and the choice of exercise 2 and 3 was dependent on performance of previous exercises. To ensure that any results inferred from the data were down to performance, occurrences of SASR exercises were observed and statistical tests were performed to determine whether there was a difference between and within each group. There was a significant difference observed (p=0.0017) and, therefore, conclusions made regarding the SASR scores would have to be approached carefully.



(a) Line plot of the overall SASR scores from pre to post for both groups

	Pre		Post	
	Game	Tool	Game	Tool
Count	9	9	9	9
Mean	124	124	137	126
SD	10.5	17.3	15.3	8.58
Median	129	120	138	125

(b) Study Two SASR Overall Scores

Fig. 6.8 Overall SASR scores from pre to post for both groups

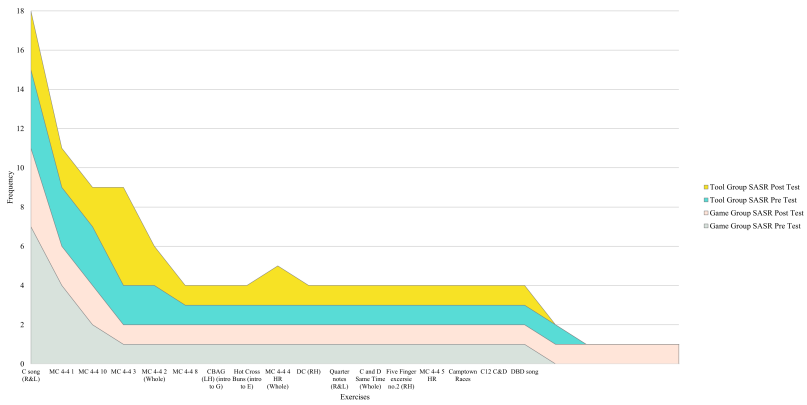


Fig. 6.9 Occurrences of exercises during the SASR tests

Reliability of Skill Tests

The reliability of the Flash Card test was evaluated using a popular measure of reliability, Cronbach's alpha and the results showed that there was high reliability for the measure of recall time (alpha = 0.938) and the same was found regarding the recall accuracy (alpha = 0.865). The consistency of high reliability for each measure leads to the evaluation that the reliability of the flash card test is satisfactory regarding all participants. The reliability was also evaluated for the SASR test, which measures the application of the reading musical notation skill. The evaluation also used Cronbach's alpha and a low reliability was found (alpha = 0.276); this was based on the independent scores of each exercise. When evaluating

the reliability of the overall scores, using Cronbach's alpha, the reliability was moderate (alpha = 0.671). The difference of reliability between the two score measures is consistent with the scores described above and rational for this is describe in the discussion.

Validity of Skill Tests

Is the Flash Card test indeed measuring a learner's ability to match musical notations to specific keys, and can the same be applied to the SASR test for the application of this skill? To answer this, an evaluation of the construct validity was conducted with the reasoning that if the construct validity is adequate, it should converge with the measures of skill acquisition and application with the self-reported ability of each participant (i.e., participants who claimed to be competent musicians should score higher in each test, and vice versa). Performance scores were consistent with each learners ability that they had self-reported. For example, participants who stated they had a higher number of years of training or experience reading notation were faster at recognising the musical notation cues in the flash card test and required less errors to correctly guess each cue. Furthermore, this correlated with the scores on the SASR tests in that more experienced participants played with the tempo more accurately and with more accurate form (i.e., with stronger finger and hand dexterity and less mistakes). Based on this, one can safely assume the convergent validity of both tests. The internal validity was ensured as there was no other factors that would have helped to increase each participants ability to read music however, the short practice times were not reflective of real-world practice scenarios (where one would learn over much longer periods of time). The randomness of the questions and exercises for both tests does reduce the validity (i.e., the instrumentation validity). However, the lack of significant difference between the questions for the Flash Card test ensured that this was not the case, but the same cannot be said for the SASR tests. As the participants practiced in a lab-based setting (a controlled environment), one could argue that this lacked external validity as it was not an accurate representation of home practice environments which are typically full of distractors. Finally, the practice effect also must be considered and taken into account regarding the improvement of scores for both tests. It could be argued that the positive increase in score from pre to post might simply be related to familiarity of the tests as well as the practice the pre-test offered.

6.4.3 Opinion Data

A comparison of average educational Likert scores between each group was conducted. Using standard T-Tests revealed that was a significant difference between the two groups ($P<0.05$). In regard to the usability scores there was no significant difference between the

two groups. Comparisons were also evaluated between the two groups regarding competency and autonomy. Standard t-tests revealed that there was a significant difference between the two groups regarding competency ($p<0.05$) as well as autonomy ($p=0.007$). Thus the only Likert score that was not significantly different was that of usability, which was the expected result. When comparing the game against the previous studies scores, there was a significant difference between all criteria that comparisons could be made for (educational, usability and competence rating). Specifically, the difference between challenge and skill (where the game was previously rated low) had increased and whilst there was not a significant difference in these two specific scores from the previous study to this study, the overall score of competency was significantly different.

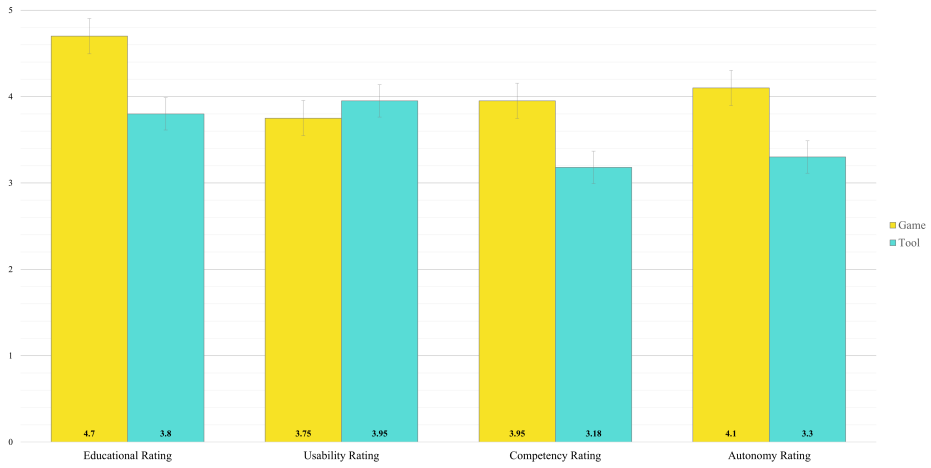


Fig. 6.10 Bar graph showing the Likert scores for educational, usability, competency and autonomy

The reliability of the Likert scores for each criteria was evaluated using Cronbach's alpha. Specifically, the measure for educational rating between both groups was moderate (alpha = 0.493), the reliability of usability assessment was moderate (alpha = 0.443), competency score reliabilities was somewhat low (alpha = 0.362) and the reliability for the autonomy criterion was the highest (alpha = 0.544). Thus, the evaluation of the reliability for the Likert score criteria was overall moderate, besides from competency being rather low and autonomy being the highest.

One of the main behaviours that was observed related to how each participant used their hands during the practice session and the following post-test. Participants playing the game were forced to place their hands in a typical five finger position when playing as this was the control schemed for controlling the character; not only this, but hand placements were important when playing notation during the enemy phases of the game as quick playing was required to avoid losing. This was reflected in the post test as well as participants who played

the game naturally placed their hands in these positions and found playing the notes seen (especially in the application test) with less frustration than observed in the pre-tests. This observation was also highlighted in regard to the use of rhythm as participants who played the game, which had a high amounts of musicality and strong rhythm components, were much more confident playing to the tempo of the post sight-reading tests. Another important observation to note was that of general behaviour towards the time of the practice session between each group. Participants in the typical practice tool group exhibited signs of wanting to finish early and were ready to complete the session as soon as the time was called. In comparison, it was difficult to stop participants playing the game and many stressed that they wanted to finish a particular level or scene before finishing the session; all participants that were in the game group voiced their interest in future studies (where the practice tool group were not as excited to participate again). To improve upon the game further, specific changes were stated by participants and general changes were found, these include:

- Showing the note name when a successful note was played on a notation
- The enemies design did not particularly match the overall design of the game
- The menus and UI were easy to use but their design did not match the game
- The 'stacked notation' was tricky to understand and participants would prefer to see longer patterns rather than stacked ones (which also reflects real world applications)
- Colours were used as a default option for the notation but many participants did not want this and turned this option off; future iterations should have this option off by default
- Whilst the arena was fun, the difficulty curve and looping was too fast and abrupt – efforts must be made to ensure that this is balanced
- The metronome was useful to keep in time but the sound was too jarring and the visuals were not obvious enough
- Participants wanted to see their score and this should track over time: how many notes played in a row and how long a rhythm tempo was kept up for should be implemented
- The tutorial was too short and required too much reading – a more involved approach would be a better implementation
- Surprisingly, all participants found the cosmetic items in the shop the most appealing and wanted to see more items of this nature

- The quest system was received incredibly positively and participants sought to complete each challenge – efforts must be made to increase the number of challenges and ensure that these can be completed over multiple levels

6.5 Discussion and Future Considerations

Below is a discussion of the results concerning the quantitative and qualitative data of the study before a discussion of the overall perspectives of the data as a whole. Finally, limitations of the study are offered before outlining the future considerations that this study has help to define.

Quantitative Results

When observing the data regarding the flash card test results, the key takeaway was that both groups performed significantly better in the post-tests compared to the pre-tests. This result is even more significant as the time allotted for practice (15 minutes) was so small. Whilst there was no significant difference in recall time between the two groups, the difference in improvement in regard to the recall accuracy indicates that the game group improved more so than the tool group. This observed difference in scores may be due to the nature of the practice in each group. The participants who used the game were forced to place their hands in specific positions, which may have led to increased memory through repeated use of specific muscles. Additionally, the use of repeating patterns matched with a musical accompaniment may have led to stronger associations with practice and thus helped to increase how comfortable participants felt using the keyboard, an idea also evidenced in previous primary research. Finally, unlike the practice tool, the game penalised participants for incorrect mistakes (a negative sound, screen shake and eventual loss of health), which may have reflected into their performances i.e. associating incorrect notes with negative consequences may have led to more a careful and accurate approach in the testing phase.

Whilst it is safe to infer that the data shows each participant improved from pre to post for the overall SASR scores (and that participants in the game group had a significantly higher increase than the practice tool group), this is not the case when observing the individual SASR exercises. This is due to the nature of the test, as the exercises varied depending on performance, so the up and down results from exercise to exercise is to be expected. Out of the three SASR exercises, the most important exercise is the first, as the difficulty of the exercise was similar across all participants (they all received very similar notes). The variation of scores which is observed in the next two exercises is not a negative observation

but can be attributed to the nature of the test, as the exercises increased or decreased in difficulty depending on performance. Analysing the data closely, it appears that the game group does improve in regard to the overall score and in the first exercise more so than the practice tool group. Reasons for this improvement may be due to the nature of the practice solutions. Whilst observing the practice tool groups; participants used mostly one hand and a limited number of fingers - they looked less composed than the game group who were forced to use their hands in specific places on the keys. Furthermore, the game also had additional elements such as music, specific musical motifs/patterns to play and made use of phrases which require hands/fingers to be in specific places. This may have helped participants feel more comfortable using the keyboard in a performance setting.

Qualitative Results

The Likert data showed that the game was rated higher for perceived educational value, competency and autonomy. It is possible the difference in score regarding the educational rating is related to the context of the questions being asked. When asking how educational the game was, it would be expected that participants rate it highly because they did learn something and the nature of the concept implies it should not be very educational, whereas it would be the opposite for the practice tool as participants expect it to be highly educational and judge it based on this very context. The lack of difference in usability rating was expected as the game featured a starting tutorial and the practice tool was a simple concept to understand. What was apparent from the interview stage was that the game was relatively easier to use and understand as it guided participants through the game and used common tropes found in games with which they were already familiar. Whereas, on the other hand, the tool required participants to ask more questions on understanding each option they had a choice of. The difference in autonomy was to be expected as the game features much more choice than the practice tool (different paths, choices of items etc.) as well as the desire to explore the game being rated much higher because participants wished to explore a game world much more than making static choices on a screen. Finally, the observed difference in the competency rating was expected as the game should elicit higher amounts of engagement and the observations highlighted this further; again, the initial reaction to those who had not seen the game was incredibly promising.

As mentioned above, it was important to compare the game from previous studies to ensure that feedback received had a positive impact on the iterative development cycle. It was clear from previous studies that the game was perceived as fun but was difficult to understand/use as well as lacking any educational impact, from the participants' perspective at least. The comparisons clearly show a significant improvement in the areas the game had

been lacking in this regard. Whilst there was no significant improvement regarding perceived challenge or the feeling of required skill, the overall significant difference of competency shows that the changes to the game had a positive effect and future changes would also reflect this effect. Key areas of frustration (such as using the menu and a lack of tutorials) were also rectified and overall participants experiences appeared to be much smoother. Finally, the issues and bugs that were highlighted in the previous study were no longer major issues and were mostly resolved; however, there were some new issues that had appeared and fixes would be required before conducting further studies with the game.

General Discussion

Whilst there were some limitations of this study such as the lack of standardisation and limited time of practice, one can still infer from the results that the game helped to improve the acquisition of notation reading skills just as well as the practice tool, if not more so in regard to accuracy and real-world application (i.e. regarding the basic tests of sight-reading). Regardless that the questions and exercises varied for each participant, the results still demonstrated a significant improvement from pre to post for each participant and the game group had improved more so regarding recall accuracy and general scores on the SASR tests. Reasons for this are outlined above but it is important to also note that the game does not only offer a more engaging practice environment but also that observations made demonstrated the game improved overall confidence at the keyboard and improved the form of playing (how participants conducted themselves when using the keyboard was more sophisticated). Finally, the improvement from pre to post test scores is rendered more substantial by the short practice time allotted for the study; a significant difference in score in such a limited time is a worthwhile result by itself.

Evaluating the Likert style data showed that the differences in engagement between the two groups was significant and this was expected (as a game version of practice should naturally elicit higher amounts of motivation relating to the concept of ‘fun’). This significant difference is also a result of the high score autonomy received from the game group and is expected – the game had lots of different choices and a multitude of actions that could be carried out during the session. The game and the tool were both easy to use and the expected result would be either they would be rated similarly regarding usability or that the tool would be rated as easier to use due to its simplicity; it was a satisfactory result to find that the game was as easy to understand and use compared with the practice tool. Notably, the significant difference between the two groups rating of education was surprisingly, however this can be a result of the context this question is posed and the expectations of each participant – as mentioned previously. Finally, feedback from the Likert-style questions and observational

data provided valuable insights into what changes must be implemented to improve usability, understanding and engagement of the developed game.

6.5.1 Pilot Study Limitations

The key issue which persisted on both the flash card tests and the SASR exercises was lack of standardisation. This led to difficulty inferring any meaningful result from the SASR data. However, at the very least, each group had improved from pre to post regarding the overall and first exercise, which can still be considered a significant result. Another issue to consider, and perhaps one that could be regarded as a confounding factor, is the overall improvement observed is not just a result of the intervention period but also of comfort; participants felt more at ease and understood the concept of the exercises and tests in the post test and thus they improved based on this alone. This 'practice effect' should be carefully considered in future testing. Whilst there are some limitations of the skill tests, it is safe to assume there was an improvement from pre to post and the game may still have better potential to improve the skill of reading music more so than a typical practice tool. Whilst there was moderate reliability of the usability questions posed, there was a lack of validity in regard to using existing questionnaires found in the literature which perhaps reduce the potential of replication for future studies. This also applies to questions which were used to assess engagement of each solution. Improvements from the previous study were considered and implemented, however it is still important to revise these questions and refine them further, especially considering the reliability of the Likert scores pertaining to competence was rather low.

6.5.2 Future Considerations

Now that limitations of the testing methodology have been established, future studies will ensure these will be rectified by standardising tests and creating custom versions of sight-reading exercises. However, a key objective which has not been considered in regard to the overall research aim is how engaging and effective these solutions are in a real-world scenario and how one could empirically measure such a concept (another key issue missing from the existing solutions). This real-world practice over extended periods of time will also help to negate the practice effect that may have been observed. The intention now is to ensure that the developed prototype is more engaging over extended periods of time and this can be measured empirically through longitudinal studies, making use of telemetric data of participants gameplay; thus ensuring that video game practice yields higher amounts of engagement and therefore improves a given skill more so than typical practice. In addition to

this, it is important to consider the questions which will help reveal how engaging and usable the game is by considering further research in each of these domains. Finally, feedback from the Likert-style questions provided valuable insights into what changes must be implemented to improve usability, understanding and engagement of the developed games. Towards this, the team commenced work leading to an improved game in line with the above feedback as well as initiating a longitudinal study which aims to answer the questions posed above.

6.6 Chapter Conclusion

In this chapter, the development of the RPG style game, 'Note Reader Adventure' was discussed in which specific insights and inspirations were mentioned that helped the further development of this game. This is followed by the third study, a pilot study which is used as a basis for future longitudinal experimentations. The results showed that the skill acquisition tests were appropriate in determining a learners ability to match musical notation to specific keys but the tests for the application of this skill were not quite as reliable. Future work includes the development of a custom sight-reading test to ensure standardisation and reliability of the application tests as well as using a set of notations and exercises (rather than random ones). Finally, questions pertaining to competence are revised to ensure that higher amounts of internal consistency are found and that future researchers can make meaningful decisions based upon this. Going forward, the developed game is refined and improved based on the feedback and observations before being used in a longitudinal study which is founded on the pilot study; limitations of the pilot study are considered and improved upon to ensure that this method of assessment if validated, reliable and replicable for future testing purposes.

Chapter 7

The Crypt of Notation: Real World Applications

7.1 Chapter Introduction

The previous chapter broke down the pilot study that was used to build a more robust methodology of assessment and to ensure that the prototype training game was at a standard which could be used in testing in uncontrolled environments (i.e., remotely in learners homes). It was found the game could be played without intervention but further developments were required, particularly of certain bugs and ensuring that the onboarding experience was refined to ensure a smooth user experience. The pilot study found that the game could be as pedagogical valuable as a market standard trainer and the methods for assessing the skill of reading music were adequate, with the need for further refinement. These key limitations of both the game and the methods of assessment were considered and key changes were developed regarding both the tests and game.

Within this chapter, these changes are discussed in detail. The game was developed further, focusing on onboarding, in-depth narrative, smoother UX and with major development to the overall design and fixing of the bugs found. These developments culminated in a concept which was as close to a game as possible whilst still retaining valuable pedagogical elements, the game was titled 'The Crypt of Notation', and the various additions are initially discussed within in this chapter. The key limitations were considered and the tests were improved; the Flash card test did not rely on randomised choices of questions but followed a progressive series of questions, whilst the Reading test (formerly SASR) was developed from the ground up.

The study is discussed in detail, in which participants practiced with either the game or the comparative standard practice tool for a total of 5 days across a period of one week. The main outcome of the study was to ensure that the novel training game was more engaging when compared with a standard training tool and this increased engagement, in conjunction with the unique practice style, would help to acquire the skill of reading music, or improve it, more so than the comparative tool. The chapter delves into how participants were recruited for such a large-scale study and the various hurdles that were faced during the process, before discussing the data of the 30 participants that completed the study. Results showed that the game improved the skill of reading music more so than the training tool whilst also receiving higher ratings across all criteria. These results are significant and help define a new approach to practice using game-based learning that can offer meaningful and transferable skills to playing and learning key-based instruments. The study was not perfect and the limitations are discussed which help define key future directions not just of the study but that can be applied to the research in a wholly way.

7.2 The Game

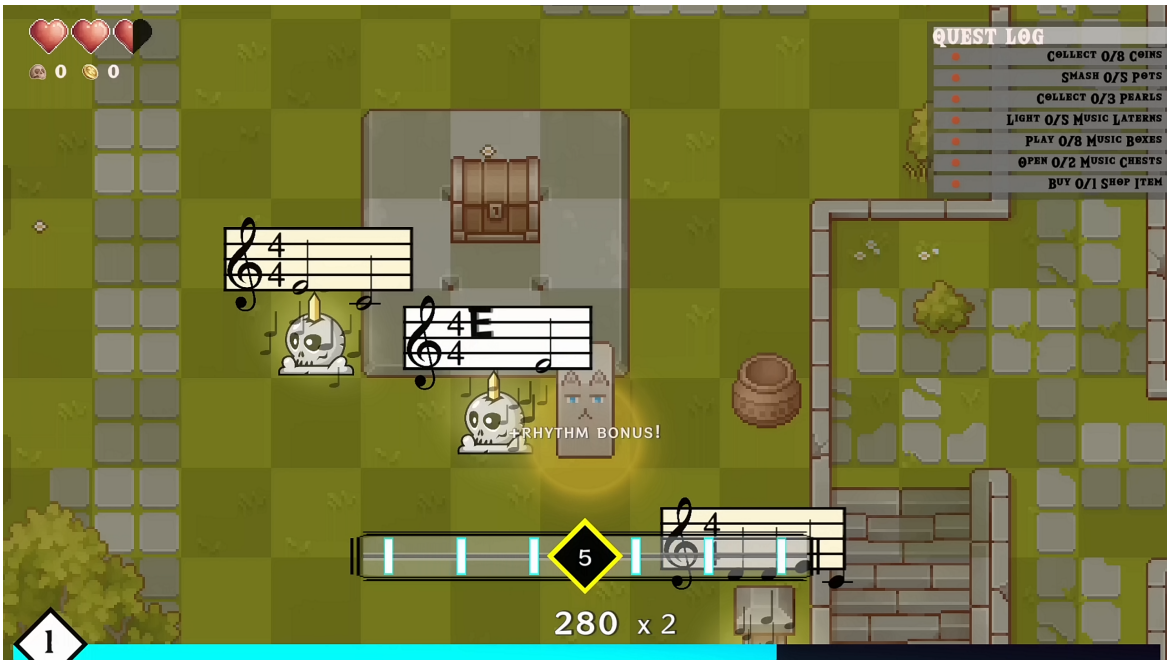
Once the pilot study had finished and the results were analysed, the next round of development begun for the 'Note Reader Adventure' game. As the game had been so positively received, it was important to add personality and depth to the game, to help players build their own personal relationships with the story and characters found throughout the game. Therefore, a short narrative was created and inspired by the theme of the game as well as creating a title which would be less functional and would inspire creativity. The final title that was decided upon was, 'The Crypt of Notation', which was inspired by the *Crypt of the Necrodancer*, as players navigate crypt like levels in which notation is the core mechanic. The story for the game is shown to players during the beginning phases and various characters help to continue this story throughout the game. The story revolves around a main hero character, Maalik, the guardian of purgatory. Maalik's evil counterpart, Yalla, a pure evil and spiteful entity, has stolen the songs of Maalik and corrupted the afterlife of the souls that exist in Maalik's crypts. Maalik calls upon the player to help him recover the stolen songs and battle the forces of evil that are spreading throughout purgatory. Yalla can only be defeated by recovering the songs and restoring the balance to Maalik's crypts; it is up the player to fight against evil by playing funky beats and thus ensuring that Maalik can restore peace to the corrupted world.

The overall UX was improved by ensuring that the particular game elements were more obvious, the UI was altered to be more logical and easier to understand, the tutorial became its own level and players were automatically shown the skill tree menu upon their character

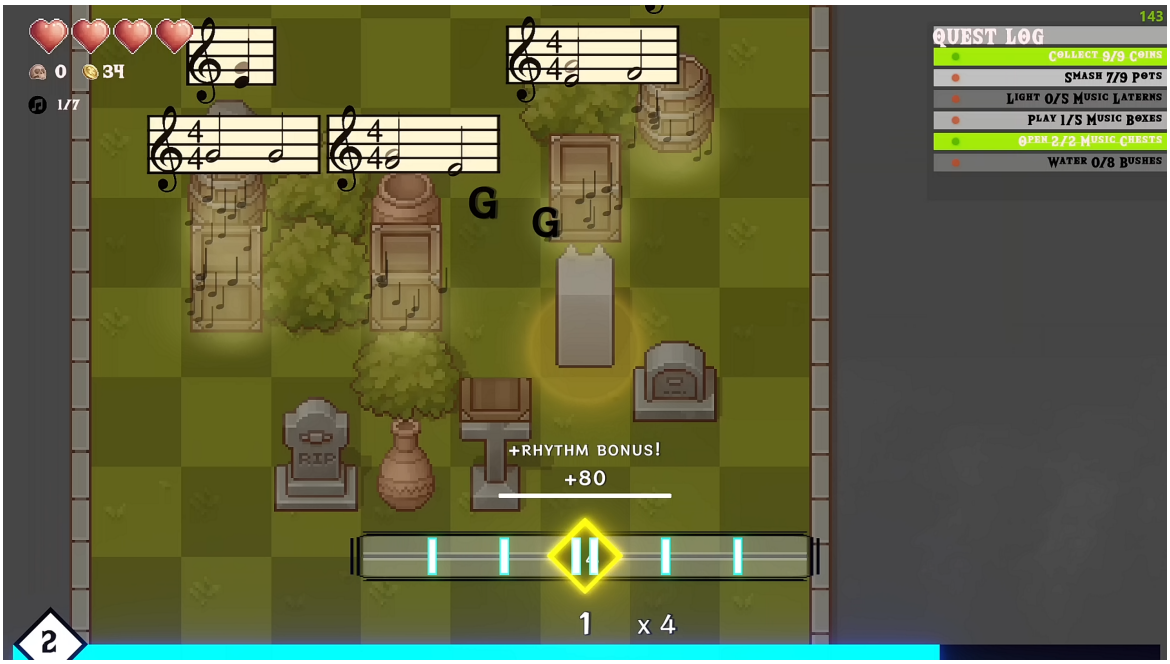
levelling up (as observations showed that players would often forget about the character skills). The design of the game became more intricate: the UI was polished in which a specific font was used throughout to help create a more specific theme for the game, the metronome visuals were improved, helping players to follow the tempo more fluidly and without frustrations. Other items were implemented based on the feedback from the pilot study: showing the name of note on correctly played notation, not having colour as the default option (but allowing this to be changed through the menu) and adding detailed statistics about each players' game in the menu such as total score, total deaths and highest streak achieved.

As the stacked notation was confusing to the participants, the design of notation was changed. Notation appeared brighter in the game and when players would guess the first note of the notation correctly, it would highlight in an even brighter shade, flashing green or red on correct/incorrect guesses. To overcome stacked notation, longer notation sprites were added instead of layering smaller notation sprites atop one another. This increased the amount of complexity of the notation by adding phrases of up to 8 quarter notes (or any variations which notes could be subdivided into, for example, 4 quarter notes and a whole note). Another common critique was the design of the enemies, in that they were not in style with the game and their movement did not match to any rhythmic components. A substantial search for online assets as well as hand drawing artwork help build an extensive library of sprites and animations which was incorporated into the game, leading to a design which was cohesive and fitting with the overall theme. Not only this, but enemies moved to the beat of the tempo and backing track by 'jumping' from one tile to the next, often towards the player or a certain object. The extended library would also increase the quantity of cosmetic items available to purchase in the store, as well adding additional functionality items such as the ability to slow the tempo down and items that could interact with other items found throughout the games levels (for example, a watering can be used to water plants and gain additional coins and score). Finally, as participants in the pilot study were eager to complete each quest or mission in the game, additional quests were added which were required to be completed over multiple levels. Some quests would also require additional items which could only be purchased at the shop, with enough coins. These style of objectives would add much more depth to the game and increase the overall complexity – leading to higher amounts of invested time and effort from the player.

In terms of content, a mix of both hand-crafted and procedurally generated levels was adopted; this method was adopted due to the size of the team being mostly a sole developer and designer (plus at the same time researcher). There are 51 levels in total, 5 of which are hand crafted by the lead developer and include additional layers of game design such as narrative, secret paths and basic key/door mechanics. The other 46 levels are procedurally

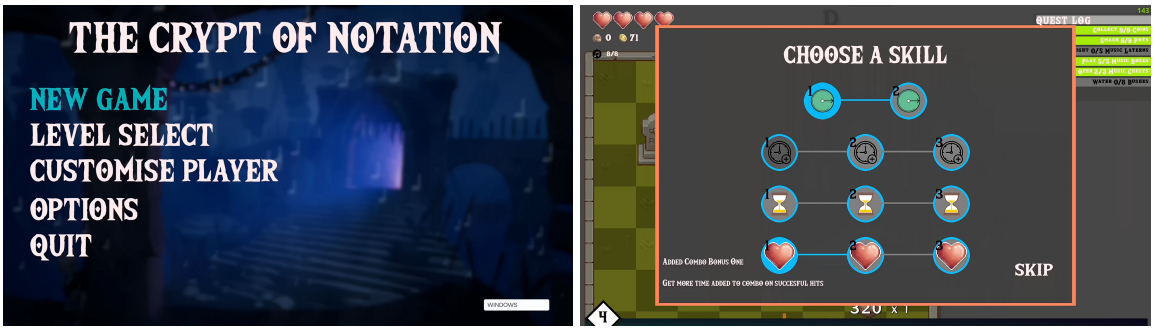


(a) Screenshot of hand-created level



(b) A procedurally generated level

Fig. 7.1 The Crypt of Notation Levels



(a) The Crypt of Notation main menu

(b) The in-game skill tree menu

Fig. 7.2 The Crypt of Notation Menu Systems

generated but still include puzzles and intelligent enemies. The levels were generated using a series of nested for loops (i.e. looping through a series of x and y positions within a given length) and placed a random choice of tile which can be provided within the Unity engine Inspector. Outer walls were created first by using the outer edges of the given size before placing floor tiles within the bounds of the outer walls and then placing objects, notation and enemy tiles at random places on top of the floor tiles. The player can move one tile at a time in any given position, with additional points earned for moving to the tempo of the music. Tiles were assigned a specific 'tag' and when the player moves into a tile, it will check what type of tile it is and act accordingly; if it is something that breaks then it will break or if it is an enemy, the player will lose health. Each level exponentially increases in difficulty in relation to the size of the level, how many notations are required and the difficulty of the puzzles, mazes and enemies. Enemies spawn every fifth level to help players learn the notation before applying it with some agency (as it was established from previous studies (Brett et al., 2021, 2020) that players felt overwhelmed trying to read new notation and tackle moving objects). The hand-crafted levels feature enemies of different types and a final 'boss area' in which there is a series of waves of enemies that the player must defeat using notation and also by dodging certain attacks (again, attempting to merge typical learning game tropes with typical video game paradigms). Finally, if players do not want to progress the main story and just want to practice using the game, they can play in the 'arena'. The arena is an endless series of increasingly difficult enemy waves which use randomly selected notation, and the player can test their abilities in order to see how many waves they can defeat before losing a life.

7.3 The Longitudinal Study

Within this study, the goal was to measure the improvement of a learners ability to read music over a period of one week within their own environments (i.e., measure the real-world application of the developed training game). Participants were administered a pre-test to measure a baseline of the skill before either practicing with the novel training game or standard practice tool for a week. The comparison training tool was the same online tool (*Sight Reading Trainer*, 2016) that was used in the prior pilot study, as the results showed that it was a valid and worthwhile tool for meaningful comparison. After the week period, they conducted the same skill tests as before (with a slightly varied order of questions and exercises), and the differences in the pre/post scores will be observed. Participants will complete post practice session surveys throughout the study to measure engagement of each solution; tracking how long they play for; what they do during the session and what effect the practice had on their motivation and confidence in context to playing and learning. Participants will also fill out a final survey helping to give insights into engagement, overall usability and preferability of each solution. The intended outcome is that the game is engaged with more so (and is ranked higher regarding all Likert style questions) and therefore improves the skill of reading music more so compared to the training tool within real-world contexts of learning (i.e., not in a controlled environment).

7.3.1 Key Questions

- Does the prototype training game improve the skill of reading music in a real-world context? (i.e., outside of a lab-based setting) when compared with a market standard practice tool?
- Can this improvement of skill be applied to other areas of playing/learning (in this case, can practising the skill of reading music/playing our developed game help our learners to read a piece of music more fluently)?
- How well does the knowledge and skill acquired retain over time? (i.e., does setting of practice or nature of practice improve memory of information, especially related to muscle memory?)
- Is the developed prototype game more engaging than a typical standard training tool? (how motivated and confident does each group feel to practice?)

- Does amount of time spent practicing correlate to how much skill is improved and are there any other factors that contribute to the acquisition or improvement of the skill of reading musical notation?

7.3.2 Participants

In total, 162 participants signed up to take part in the study initially, however, the number of participants who completed the study in full was eventually 30. All 162 participants completed the initial survey sent to them which provided demographic data and helps to provide some interesting information on particular learners and their learning preferences. Out of the 162 participants, roughly 60 began the second phase of the study (the skills test) and went on to begin the practice week. The number of participants began to reduce over the course of time - some participants were too busy to complete the remainder of the study whilst others had major life events occur forcing them to drop out of the study; leading to eventual number of participants that fully completed the study to 30.

As participation in the study was completely remote, participants did not need to be based locally to the researcher and as such the recruitment could be extended globally. As a result, the total 162 participants were located in multiple countries across the world where most were based in either the UK or the USA; the map below shows the specific origins of the participants for the total 162 that had initially signed up. Of the 162 participants, the methods of learning and practice varied but there were 3 popular methods that were observed: online videos and applications, self-taught and tutor based. Interestingly, those that had claimed they were competent learners and could read notation confidently, had slightly different methods of learning that were most popular, which included: self-taught, tutor-based and books – with online videos and applications still being used but not as much as the 3 most popular methods (the graphs below help to demonstrate this difference and highlight the need for a very precise target audience when designing such learning solutions).

Table 7.1 Pilot Study Participant Demographics

	Age Group				
Demographic Information	18-24	25-34	35-44	45-54	55-64
N (Count)	4 (13%)	12 (40%)	8 (27%)	5 (17%)	1 (3%)
Gender (count)	1F	2F	3F	0F	1F
Experience Reading Music (out of ten; mean)	2.25	3.58	3.13	2.6	4
Gaming Habits mean)	1-2 Hours Per Day	Once a week	Once a week	2-3 times a week	1-2 hours a day

The eventual sample consisted of 7 females and 23 males with the majority of participants either aged 25-34 (40%) or 35-34 (27%). Most participants were either absolute beginners with no experience of reading musical notation but had a desire to begin learning keyboard or

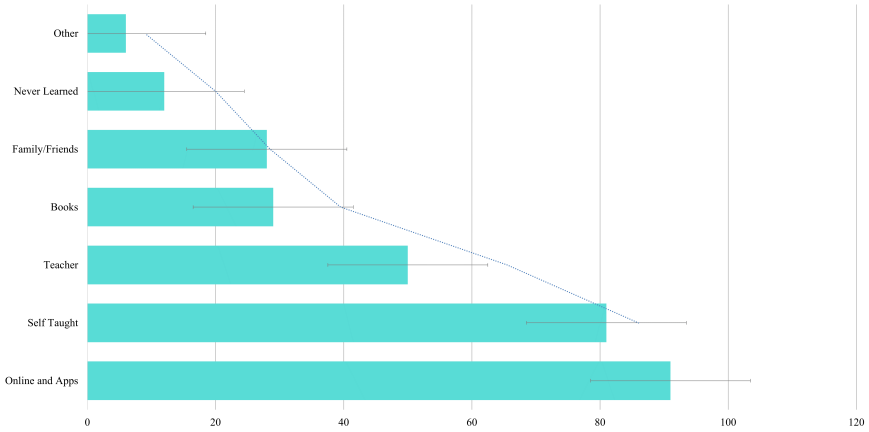


Fig. 7.3 Participant's learning habits

piano (and had tried to at some point in their lives); 5 participants were competent musicians who were skilled at reading musical notation and playing their instrument (typically keyboard, piano or both). Out of the 30 participants, only 3 stated they did not play games whilst the majority of participants played either at least once a week or once a day (there were no relationships found between age ranges and time spent playing video games). There were a total of 4 participants who did not own a MIDI keyboard (either owning no instrument or a key-based instrument which lacked MIDI capabilities), and were able to either borrow the required hardware from a friend or from the company on a loan basis.

7.3.3 Study Protocol

The initial sample size was calculated, based on the previous studies and calculating effect size: .05 level of significance, 90% power, 20% increase in score and standard deviation of 2.5 resulted in 34 required participants. This was a rather high number of participants, particularly when one considers the complexity of the study and the amount of time required for each participant to spend; thus the end result of 30 total participants is satisfactory. Initially, participants were recruited through the existing mailing lists as well as through Bournemouth University. The initial recruitment advert requested that participants meet a certain demographic, listed as:

- 18+ years of age
- Aspiring musicians who are absolute beginner to intermediate keyboard/piano learners (participants could apply if they were competent musician but beginners had priority)

- Little to no experience reading musical notation (participants could apply if they were competent in reading music but beginners had priority)
- Enjoy playing video games (ideally on a regular basis) or are interested in gamified learning in any capacity
- Ideally own a MIDI keyboard with at least 48 keys (4 octaves); there was potential to loan hardware to particular participants, where feasible

As the study was rather involved and conducted over a longer period of time than any other study, it was important to offer worthwhile incentives. Therefore, all participants were initially awarded a £30 Amazon voucher and were entered into a prize pool. The winner of the prize pool would receive hardware from the sponsor company and the second prize was an additional £50 Amazon voucher. The initial numbers from the first round of recruitment was low, and whilst some participants had completed the initial demographic survey to show interest, many did not follow through on the next stages of the study; about 5 total participants had completed the full study based on the first round of recruitment. Based on these low numbers, it was decided that the second round of recruitment would increase the incentive and other avenues to seek out potential participants were explored. The base incentive increased to £50 whilst the prize pool second place was raised to an additional £100 Amazon voucher. Additional mailing lists were consulted at Bournemouth University whilst also emailing those from the companies mailing list, whilst they may have some interest, they would not fit the ideal demographic but could still offer meaningful data. The number of participants who filled out the initial survey rose extensively and over 20 participants continued to the next stage of the study. However, only around 10-15 participants actually continued through all the stages of the study as some participants had serious life events preventing them from continuing, whilst others simply did not respond after a certain stage.

Therefore additional areas of recruitment were explored further, particularly focusing on online forums that were relevant to the research. Specifically, sub forums used on a popular website, Reddit, were used, focusing on those dedicated to music, keyboard and piano learning whilst also posting on a sub forum dedicated to academic study recruitment. Through this and advertising through LinkedIn resulted a surge in the total of number of participants filling out the initial demographic survey. Although the large number of sudden new participants was positive at first sight, it also raised questions. Upon closer inspection, many of the responses appeared to be highly similar, if not completely identical to one another; unfortunately, even with added measures to prevent such an occurrence, there had been particular answers provided either by bots or by participants using software which would fill out multiple instances of responses automatically. The issue of attempting to recruit

a substantial number of participants had required posting the advert to multiple locations which in turn had led to unwanted responses. There were precautions in place to prevent this, such as the requirement of open-ended answers and additional hidden optional items, yet the advent of intelligent software appeared to overcome these precautions. After analysing all the responses and determining the 'fake' data (which was rather obvious when multiple responses were identical and provided within an extremely short space of time), the total number of responses went from 382 to 162; 220 fake responses were removed and analysis of the results that remained could be analysed.

All participants that had completed the initial survey, and matched the ideal demographic, were sent instructions on completing the first stage of the study, the pre skill tests. Each participant was required to complete two tests, a skill acquisition and application test (see further details below). Each test the participant undertakes is downloaded from a secure server and their scores are automatically uploaded to a remote server which the researcher will have access to. It will record participant number, the time the test was taken and all the data relevant to the test itself (how many mistakes made, time taken). This data is fed into a comma separated value document which will be translated by spreadsheet software (Microsoft Excel). If participants did not complete the tests within 5 days there were contacted by the researcher; only those who complete the initial pre-tests were progressed to the next of the study.

Once a participant completed the two skills test, and their data was found on the server, they are emailed the next steps. At this stage, the participant is split into one of two groups: the control group will use a basic notation reading practice tool found on the web and the experimental group will play the developed prototype training game. The game group was guided by an in-game tutorial and the tool group were given basic instructions on how the training tool works and what each option does. Each group was required to use either solution for at least 10 minutes per session, for 5 days within one week – the days were not required to be consecutive and the time could not be stacked (it had to be 10 minutes day - 20 minutes one day did not count for two days of 10 minutes practice). The 10 minutes could be completed over multiple sessions over a day (such as, 2 sessions of 5 minutes rather than 10 minutes in one go). The minimum total practice time was therefore 50 minutes of practice time if participants only play for the allotted time required. Participants will be informed that they can practice outside the time if they wish to do so but this is not a requirement of the study. Participants are also instructed to not practice reading musical notation using other training or practice methods during the 7 days but are permitted to practice other elements of their keyboard learning. Participants were also required to fill out a short questionnaire at the end of each practice session to gain insight into what they had been playing and practising

and their general views on either practice solution (specifically, how long they had used the solution for and the effect it had on their motivation and confidence to learn and play).

After the 5 sessions of practice had been completed, participants were required to undertake the same skill tests as before, in which the order of questions were and exercises were shuffled. The difference in scores between the pre-test and post-test were measured with the assumption that both groups will have a significant difference in score (with the hope that the game groups improves more so than the tool group purely because they have practiced more as the game is more appealing than the tool). These tests follow the exact same format as before and all data will be recorded and uploaded to a secure, remote server. Following the skill tests, participants are required to fill out a survey (once again, in a JISC Form which the researcher will have access to the answers) about their experiences. They will be asked about how engaging, usable, and educationally valuable they thought their practice tool was. This will be in the form of mostly Likert style questions with some questions asking for more detailed answers (general comments rather than a 1-5 answer). This section of the experiment, in conjunction with the post session surveys, will give insight into how engaging and usable each solution was; the assumption being that the game will be used more and receive a higher rating for engagement as well as more overall positive feedback compared to the practice tool. Details of each question can be found in the appendix.

Skill Acquisition Test

As the pilot study showed the positive implementation and reliability of the Flash Card test for measuring the acquisition of improvement of the skill of reading musical notation, this was also used in this study. There was one key difference, founded on the main limitation of prior implementation of the test, relating to the standardisation of the test. Previously, the test chose a random notation from a bank of potential notations, which led to low reliability as some participants could have received the same note for every question. In this study, a specific series of notations were used for both the pre and post-tests, ensuring that all participants received the exact same questions and an even base of comparison could be assumed. Score was once again based on two key factors: recall accuracy (how many times an incorrect key is pressed before the correct one), and recall time (how long it takes to play the correct key). The notes shown all appeared in the same order and were be ranked by difficulty by following similar tests found in early stages of music theory testing (typically following music school curriculums

Skill Application Test

Based on limitations found in the pilot study that the SASR tests lacked standardisation and the specific data that made up the total score could not be assessed, a custom reading exercise test was developed. The test was similar in nature to the SASR score; however it allowed more time to read the exercise to help reflect the skill of reading music rather than the skill of sight-reading, whilst also ensuring that every participant received the same exercises, in the same order. The test showed participants a basic reading exercise (a monophonic motif) and they could familiarise themselves with the exercise by reading over it for a total of 40 seconds. Once the 40 had passed, the test would count the participant in (a count of 4) and they were required to play each note seen to both the metronome and simple backing track. Participants could navigate to a help screen before or after each session to ensure that their keyboards were connected and in the correct octave whilst also reading the instructions on how the test works. There were 4 exercises that were completed in total, where the first exercise was used mostly to help participants acclimatise to the test before being introduced to more complex exercises. Score was based on 3 factors: total correct notes, total incorrect notes and rhythm accuracy. Rhythm was measured by the time either side of the exact moment of the tempo on the note; three accuracies were scored: slow (around 0.5 seconds from the beat), OK (around 0.3 seconds from the beat) and perfect (around 0.1 or less than the beat). Score was a sum of the correct notes played multiplied by their corresponding rhythm scores whilst removing a point for each incorrect note played; a total score of all the exercises was calculated by simply totalling the scores of all 4 exercises. This custom developed test ensured that there was a standard across all participants and that the individual data could be analysed in depth.

7.3.4 Results

There were three main categories of data from the results of the study: the skill test data, the data from the post sessions and finally, the data that was extrapolated from the final surveys participants completed. The skill test data comprises of the results from both skill tests, the Flash Card and Reading Notation test - specific criteria was analysed regarding both tests. The post session survey data helped to gauge the time each participant spent practising with their given practice solution as well as how the solution impacted each participants motivation and confidence regarding playing and learning their keyboards or pianos. Finally, the end survey data helped to measure the opinion data relating to how participants rated pedagogical value, usability, competence and autonomy (both competence and autonomy being used to measure overall engagement), in which comparisons were made between the

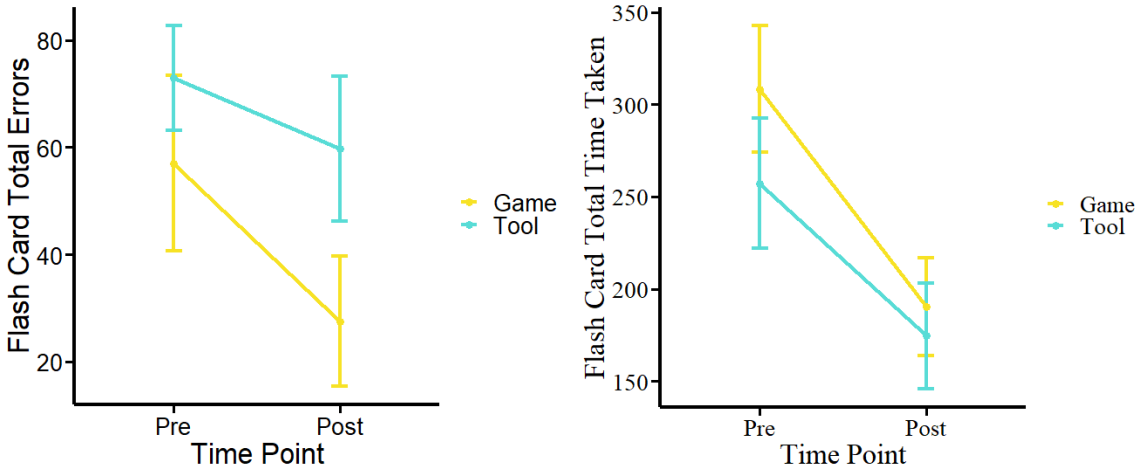
two groups. The end survey also allowed participants to feedback in their own ways on the overall experience and any reasons that may have led to specific Likert ratings.

Skill Tests

As mentioned, the skill test was split between the results of the Flash Card and Reading tests. Below is a summary of the data found for each test, including relevant reliability and validity discussions.

Flash Card Test

The data for the Flash Card test was comprised of two key criteria (in which the pilot study helped define): recall accuracy (total mistakes and mistakes per questions) as well as recall time (how much time it took to answer each question and the total of all questions).



(a) Total errors from pre to post

(b) Total time taken from pre to post

Fig. 7.4 Flash Card Results

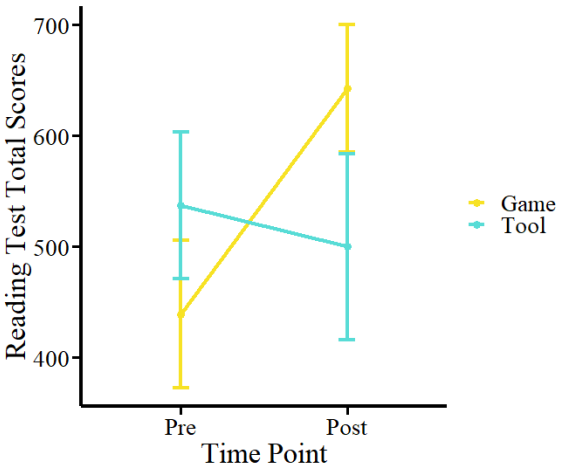
Regarding the recall accuracy, it was found that only the group which used the game for practice had a significant difference from pre to post ($p<0.05$); the data shows they had made fewer mistakes, rather than a significant difference showing they had more mistakes. Comparing between the groups, there was, not surprisingly, a significant difference between the groups regarding their differences of total mistakes made from pre to post ($p= 0.002$). This result shows that the game group had far less errors from pre to post and the difference compared to the tool group was significant.

When analysing recall time scores (i.e., how much both groups had improved regarding time required to answer correctly), it was found that both groups had improved significantly

from pre to post. When comparing between the groups, there was no significant difference between both groups (p=0.191); the result does show that the game group had improved more than the tool group, but the difference was not great enough to be significant. In summary, only the game group had improved from pre to post regarding recall accuracy, however, both groups had improved in context to recall accuracy in which there was no significant difference between the groups.

Reading Test

The data for the reading tests were split into three smaller items, which the total score is based on. These smaller data criterion were: total correct and incorrect notes played and total rhythm score (measured with three scores: slow, OK and perfect). Each of these scores were totalled from all four exercises as well as comparing the total scores of the individual exercises to determine if there was a specific exercise which skewed the overall summaries. Below is a summary of the overall scores summarised from the individual scores as well as a breakdown of the individual scores from each exercise.



(a) Overall Reading score from pre to post

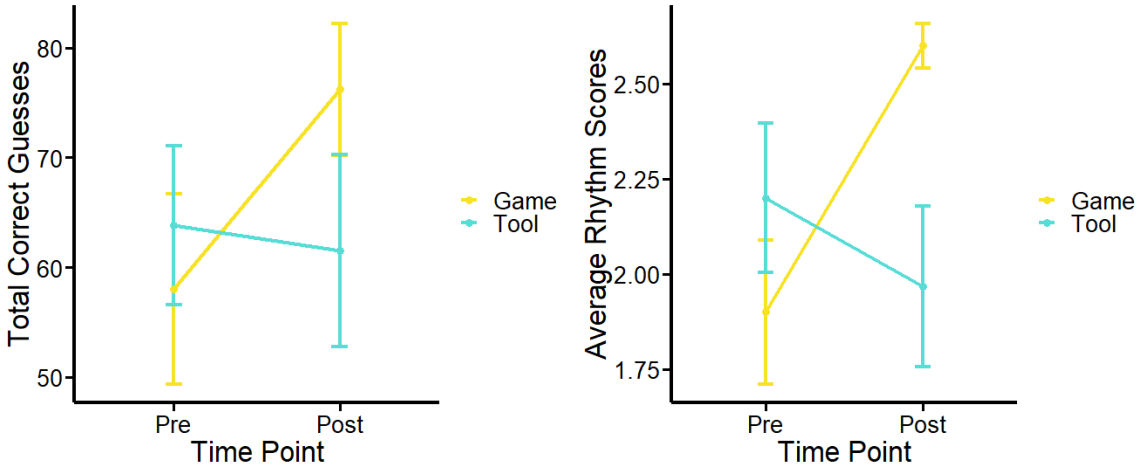
	Pre		Post	
	Game	Tool	Game	Tool
Count	15	15	15	15
Mean	439	537	643	500
SD	258	257	223	324

(b) Study Two Recall Accuracy Scores

Fig. 7.5 Overall Reading Test Results

Regarding the overall total scores (i.e., the sum of the individual exercises), only the game group had improved significantly from pre to post relating to the total score, correct and incorrect notes played and rhythm accuracy. As a result, there was a significant difference between the groups for each of these criterions and it can be concluded that the game group had improved significantly higher than the tool group (over a 30% improvement in all categories).

When reviewing the total scores for the individual exercises, the game group had a significant improvement from pre to post whereas the tool group had only a significant difference on exercise 3 (p=0.014). Upon further inspection, it was apparent that the significant difference was a negative one (participants scores were significantly lower from post to pre). This is also reflected within the game group as all scores are lower on exercise 3, however the game group still had a significant improvement, whereas the tool group was the opposite. The results showed that the game had significantly higher difference in score when compared to the tool group ($p<0.05$).



(a) Total correct notes from pre to post

(b) Average rhythm scores from pre to post

Fig. 7.6 Reading Test Specific Results

From these results, one can safely assume that the participants who practiced using the game had improved in the reading test significantly more so than those who practiced with the training tool; the difference in score is substantial and because there was an even difference on all exercises, there is no particular exercise that skewed this result (helping to ensure validity of the reading tests).

Tests Reliability

In order to ensure reliability (specifically, the internal consistency) of each test, it was important to investigate that the specific criteria of each skill test was indeed measuring one's ability to either recall musical notation or read it within the context of real-world applications (i.e., reading the score with a musical backing track). For the Flash Card test, the two criteria were recall accuracy and recall time. Using Cronbach's alpha an acceptable internal consistency was found (alpha = 0.52) within both groups. The same process was applied to the reading notation test (the application test), with additional aspects to consider.

The overall score which was a sum of the individual exercises was used, specifically using the rhythm, correct and incorrect notes in conjunction with the total score that was received for each individual exercise. The reliability of the reading test was higher than the flash card test (alpha = 0.73) and is an acceptable internal consistency for a test which had never been administered before. Whilst the reliability is somewhat low for both tests, it is important to note that there were few measures which were used to gauge both test scores and this inherently will lead to difficulty in ensuring reliability of the tests. The reliability being low as a result of the few measures that were used is highlighted by the difference in reliability between the two tests: as the Reading test used four criterions for assessment and the Flash Card test only used two, the Reading test shows a higher reliability - indicating the Flash Card test must begin to consider how it can further measure the acquisition of the skill of recognising musical notation.

Tests Validity

As with the pilot study, the construct validity was evaluated by ensuring that the scores from both tests converge with the ability of the individual participant (which was self-reported); not only this, but the scores should also be consistent from pre to post in correlation with the skill level of the participant. The data does indicate that the participants who were ranked higher in overall musical skill and competency scored higher on both the Flash Card and Reading tests (across all assessment criteria), leading to the safe assumption of the convergent validity for both tests. Ensuring internal validity was more difficult when compared to the pilot study, which was conducted in a controlled environment. As the tests were conducted in home environments over a period of a week, one can assume that this is a good representation of real-world scenarios and negate the practice effect from the pre-tests. However, due to the uncontrolled environment, there may have been other factors that helped participants score higher, such as additional practice or learning and time spent at the instrument in general. To help overcome this confounding factor, participants were asked to state what other activities they had been engaged in with their instrument during the practice week as well being asked to not practice reading musical notation outside of their particular practice solution for that week. For the most part, the majority of participants had not been practising on many other skills and were more focused on practising with their given solution. There were participants who had practiced other elements of playing their instrument such as scale and repertoire practice but this was consistent between both groups and as such an even baseline for comparison can be assumed; one can also begin to safely assume that the difference in score is also only due to the time spent (or lack of practice) with each participants practice solution.

Post Session Surveys

For the post sessions, there was two main areas of data: quantitative and qualitative. The quantitative data was in the form of Likert style questions which measured time spent practising, motivational and confidence differences regarding playing each participants instrument after the practice session had finished. Time spent practising was ranked by 6 descriptors (mentioned above); for the purposes of analysis, these descriptors were given a numerical value from 1 to 6 (6 being the most positive, i.e., the longest amount of time spent practising). The median value was calculated for each session and this value was compared between groups to help gauge how engaging each solution was; with the assumption that the more time spent practising or playing, the more engaging the solution must be. When comparing the time spent practising, it was found that the game group had a significant difference to the tool group ($p = 0.007$), indicating that the participants in the game group engaged with this solution much more than the tool group (where the game group's median was '15-30 [minutes of practice]' and the tool group's was 'Only for the allotted 10 [minutes of practice]'). Another interesting insight into the data was plotting the time spent practising over the sessions and how this fluctuated. For the game group, there was a consistent amount of play time whereas the tool group began to lower over the sessions with a steep decrease in the final session. Regarding the motivational scores between the two groups, there was a significant difference between the two groups ($p<0.05$) and this was also true for the ratings of confidence ($p = 0.005$); both results indicate that the game group was rated much higher than the tool group regarding both of the ratings.

The qualitative data of this portion of the study was in the form one particular optional question relating to specific elements that participants felt may have helped improve any specific skills whilst practising (further details disclosed above). The data helped to reveal insights into what specific areas of playing keyboard were improved using the game more so than the tool. Data also helped to improve specific game elements and highlighted positive areas of the practice tool which were mentioned regularly, that could potentially be included in next round of the games development. There were reoccurring themes that were observed in the answers, which included:

- A key difference between the game and tool feedback was that the game was useful for improving hand positioning and helped participants feel more confident using two hands together; feedback regarding the game was the opposite of this and most participants felt as though the practice style would lead to poorer playing form
- Because of the audio effects and feedback, participants who played the game highlighted that they were not looking at the keyboard whilst playing. This results indicates

Fig. 7.7 Post session Likert ratings

that practicing in a game-based style (in which multiple musical elements are tied together) leads to greater memorisation and stronger muscle memory

- One of the main issues found was that the metronome in the game was not in sync to the backing track. This is mostly due to the sound of the metronome having a slight delay before the actual sound is heard – an issue that was only noticed once the study had begun
- Another reoccurring issue that the game faced was a lack of keyboard setup which led to confusion when participants were manually determining the correct octave to play in
- The in-game puzzles were received positively but due to their repetitive nature and lack of variation, they became boring
- A key issue was overlapping notation on game objects. As the content was procedurally generated, some objects were placed next to each other and when their notation was shown it would often cover another notation – leading to confusion of which notation is actually being played
- The game's tutorial was required but many participants claimed they wanted to see tutorials throughout the game and be shown specific elements such as, using the skill tree and shop

- The main positive takeaway for the tool was the variation in modes of practice (such as pure ear training and scale practice); this should be fed into the game in smaller mini games or puzzles which require additional skills
- A final theme was that the training tool had no easy setup or tutorial and participants wanted to know what specific options would do – the use of tooltips and consistent small tutorials is key for a smooth user experience
- Overall, feedback for the tool was negative, most participants completed each session out of necessity rather than for enjoyment. As one participant states: "...honestly I do not like the practice tool and would stop using it immediately [outside of the study]"

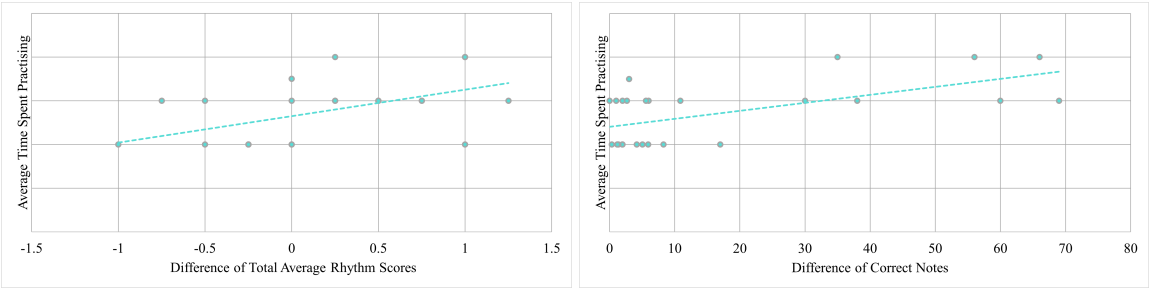
A final insight into the overall reception of both solutions was the quantity and depth of the feedback given for this question. For the most part, most participants in the game group gave feedback after every session and their feedback was detailed, enthusiastic and personal. In comparison, feedback on the tool group was sparse, overall more negative and was more functioning related rather than personal requests. This helps to highlight the much more positive review of the game when compared to the tool and helps to further strengthen the difference of engagement between both groups. Whilst certainly not a quantitative result, it is still worth mentioning as it helps to highlight the difference in enthusiasm and personal connection between novel and typical forms of practice relating to key-based instruments.

As the assumption of this study was that the more one practised, the more they would improve a specific skill and gain confidence with playing their instrument, it was deemed imperative to assess this within the data. Therefore, the time played data was correlated with the scores of Flash card and Reading tests. Each specific criteria for assessing both tests was correlated against the median play time for each participant (that is, recall accuracy and time for Flash card and all relevant criterions for the Reading test). Overall, there was a positive correlation for every score, particularly for rhythm ($p = 0.51$) and overall scores ($p = 0.43$) on the Reading tests, the recall accuracy ($p = 0.59$) and time ($p = 0.48$) for the Flash card test.

Thus, the hypothesis that the more time one spends practising, the more their skill will improve, can be accepted. However, the correlations are not all extremely strong and there are other factors, which are discussed below, that are factored in to help improve the skill of reading musical notation that are unique to each group.

End Surveys

The final surveys that participants completed were related to how they personally rated pedagogical value, usability and engagement for their given practice solution. Participants



(a) Correlation between difference in average rhythm score from pre to post on Reading test

(b) Correlation between difference in recall accuracy from pre to post on Flash Card test

Fig. 7.8 Practice time correlations

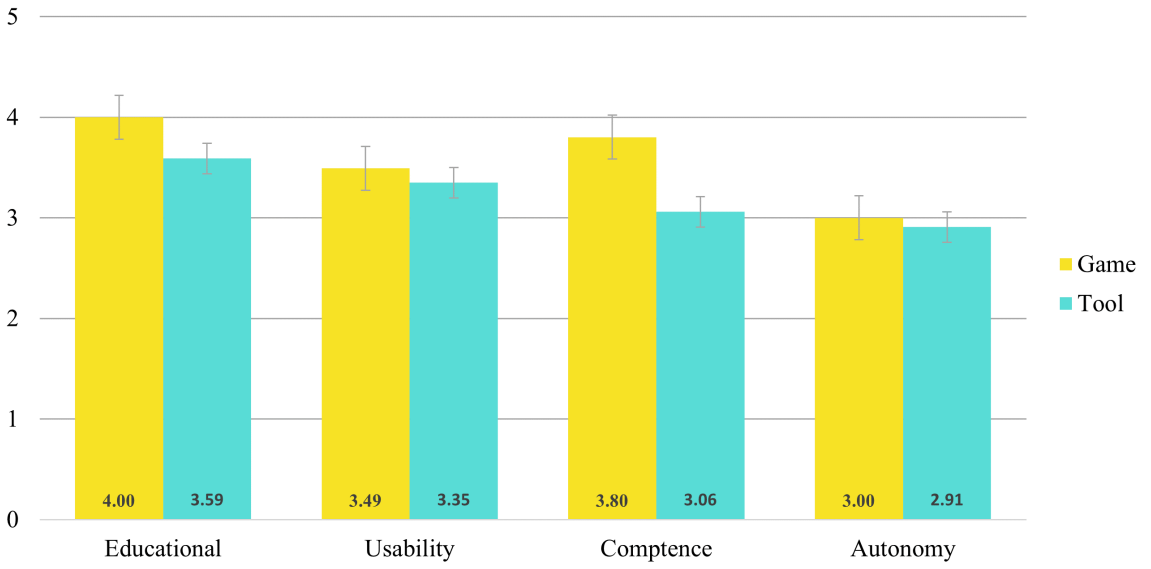


Fig. 7.9 Final survey Likert ratings

also had the option of providing additional feedback into why they gave particular ratings. As mentioned in the protocol, participants were asked to provide a 1-5 rating on specific questions, which would be totalled and used to assess the above categories. For the analysis, each question that related to a particular category (for example, competency rating was comprised of 5 questions) would be totalled and the average of this score would be compared between the two groups. There was only one significant difference in rating, which was the rating of competency ($p = 0.0008$), whereas all other categories were similar in rating. The open-ended questions help to determine why these findings are as such, which is discussed in further detail below.

To help determine that the questions posed regarding each category of assessment was indeed measuring that particular category, the reliability of the questionnaires was analysed

(i.e., ensuring internal consistency). As feedback from the pilot study had been taken onboard, it was assumed that the reliability should therefore be at a higher level; this was true as all reliability scores had improved greatly from the previous study. Specifically, the questionnaire that related to pedagogical value was high (alpha = 0.87), the questionnaire that was related to assessing usability was high (alpha = .79), the questionnaire that measured competency was high (alpha = 0.91), and the questionnaire that was related to autonomy was the lowest (alpha = 0.56). Thus, the internal consistency of the questionnaires relating to pedagogical value, usability and engagement can be determined as high and future studies should be able to replicate similar results (with particular consideration to extending the questions relating to autonomy).

7.3.5 Study Discussion

The discussion of the results is comprised of the skill tests, post and end questionnaires and a final review of the overall themes and takeaways learned through analysis of the results.

Skill Tests

The results show that the game group difference scores from pre to post were significantly different from those of the training tools, with the exception of the recall time on the Flash Card test. Based on these results, one can safely reject the null hypothesis (the game group will not improve the skill of reading musical notation as much as the typical practice method). Whilst this result is positive, it is important to consider why this result has occurred and what other factors may have helped to impact it. The internal consistency of the tests was moderate and both tests were standard (whereas, in the pilot study, questions posed were randomised), which helps ensure that both tests are measuring the acquisition and application of the skill of reading music. Furthermore, correlations between the time spent practising and scores on the tests are positive which helps to further the argument that it was the game that had helped acquire or improve the specific skill. Whilst this is satisfactory, there must be other elements that helped to improve the games score so significantly, especially in comparison with the training tool group; a 30% or more improvement in all but one of the criterions of assessment is significant after all. Consulting the factors that impacted the score on the pilot study help reveal the additional considerations one must take in account for this study. The main umbrella factor is the nature of the practice. The increased use of hand positions and two hands playing together helped to strengthen muscle memory (which is also highlighted directly by feedback from participants) and the incorporation of musical elements helps to reinforce memorisation through equivalence-based learning; not only are participants seeing

a notation and matching this to a key, but they are also associating it with sound or a particular character or enemy. This use of music not only helps reinforce memorisation but also helps to strengthen rhythm when playing the notes in the Reading tests.

Finally, how the game builds particular emotions with practice and play has an impact on the post-test performances. The sense of agency that is found throughout the game (beat the enemies before they reach the player, complete the puzzle before time runs out) builds a strong negative emotion with incorrectly guessing a note and this is reflected in how accurate participants responses were in the post Flash Card test. Finally, the overall positive emotion that the game associates with practice led participants to be much more involved with the study and give more in depth feedback. This positive association leads to participants generally giving more care to their post-test performances where, in contrast, those who practiced with the tool were looking to complete the study for sake of completion, not for the association and relationship they had built with the training tool.

Post Session and End Surveys

Time spent practising was significantly higher within the game group compared to the training tool group, which was the expected result. The difference of practice time over the sessions is also a good indication of engagement. Results showed that the game group did not decrease their practice time and in some cases, it was increased, whereas the opposite is found the training tool group. This highlights how engaging the game actually was and shows that with further development, such a novel practice method could have the potential to aid learners over much greater amounts of time. The significant difference in ratings of motivation and confidence correlates to the scores from the difference in scores on the skills test: those that were more motivated and felt more confident playing were found to have higher scores on the skill tests also. Such a result is significant and shows that this form of practice, whilst novel, is incredibly impactful and future researchers, teachers and developers should seriously consider how their learning can incorporate game-based learning.

Whilst the only significant difference in rating on the final questionnaire was found in competency, it should be noted that all the ratings for the game were higher than the tool. When comparing these scores to the pilot study, all areas had improved. The lack of significant difference in pedagogical value rating was not surprising as the tool is highly effective for practising reading notation. However, the fact that the game group was rated higher, regardless of a lack of significant difference, is still a meaningful result and has shown that feedback from the pilot study regarding the game has had a positive impact; demonstrating the model of iterative development and testing is an ideal model to implement. The ratings for usability had once again improved for the game from the pilot study scores,

although it did not lead to a significant difference when compared to the training tool, this is expected as the training tool is inherently simple to use. Specific feedback will help to improve the overall UX and onboarding for the game such as, a keyboard setup screen and tutorials fed into the game at certain points rather than showing all information during the beginning stage. Not only this, but participants also highlighted reoccurring bugs such as enemies getting stuck and notation covering one another, leading to a lower score for usability. The majority of participants enjoyed seeing both staves (treble and bass) but wanted to see the grand staff as well – this would reflect well into real-world applications also. Finally, feedback from both the game and training tool showed that participants would want a post-practice 'review', to highlight where they struggled the most and perhaps offer additional game levels that cater to these areas of difficulty per learner.

Whilst competency was the only rating that was significantly higher with the game group, with one participant stating, "...I think it sits outside of the normal [practice] routine for most [learners]", there were still elements which could improve this further. This includes late game levels and content being more varied and complex. Due to time constraints and lack of resources, designing hand-built levels and play testing was tricky and led to the game being not as personal as it could have been; this lack of personality and hand-crafted content will naturally lead to a lower review but is also remedied with more time and resources. Not only this, the difficulty curve and progression was not steep enough for the majority of participants, who were competent video gamers. This demographic is familiar with video games and expects more challenge – attempting to cater to a wider audience led to lower satisfaction with the primary target audience who are versed with challenging video games. Specific feedback regarding immersion also reflected areas of improvement: the narrative and puzzles requires more depth and the main bugs removed participants from the 'magic circle' (Tekinbas and Zimmerman, 2003) of the game.

The lack of difference in rating for autonomy was surprising, as it was expected that the game would be rated much higher than the tool. There were multiple factors that affected this score: the training tool did indeed have a multitude of choice and participants noted that this was useful and helped to increase engagement. Whilst participants were excited to explore the levels in detail, "...I felt like exploring every nook and cranny of the levels", they also noted the lack of variation across levels. Whilst the levels increased in size and notations, the premise was rather similar and this is due to a lack of resources which led to procedurally generated content (another case where a lack of personality is detrimental to the games design). Not only this, but the mechanics themselves could be more intricate and complex, such as adding required timings on certain items, specific patterns that are required to be recalled which unlock secret areas - the list of additions is almost endless. Fortunately,

these points can be fixed easily with more time and resources, perhaps better suited to a full-time game developer or a small team of developers and researchers.

General Discussion

Overall, the results have shown that the game improved both the acquisition and application of the skill of reading musical notation over a given period of time, within a real-world setting. Furthermore, the game was much more engaging and all Likert scores were higher for the game group. It was clear from the depth, quality and quantity of the feedback which group was more invested in the study - those in the game group were much more positive and receptive. Participants also wanted to pursue practice using the game after the study was conducted, with one participant excited to purchase the game once it had been fully developed, "If it was a real game, I would buy it!" The significant difference between the scores found on the skills test are a reflection of this positive reception. Those who practiced with the game, were more invested in the study and as such their efforts on the skills tests were more serious than those in the tool group (who were simply completing the steps of the study to simply finish their participation).

Study Limitations

Whilst the null hypothesis was rejected and the results showed that the game group was rated higher in all categories in comparison to the training tool, there were still some limitations of the study. These include:

- The practice time was self-reported and ambiguous (it lacked specificity). Whilst self-reporting is not a bad practice, the time frames participants could choose from were quite wide (for example, 15-30 minutes could mean near to 15 or near to 30 minutes – a large difference!). Self-reporting can also be inaccurate and participants should not be expected to be gate keepers of the time practiced

- Criteria that measured both the Flash Card and Reading tests were not extensive and this lowered overall reliability (i.e., only measuring recall accuracy and time where other factors could also help to determine skill acquisition/improvement, leading to an increase in internal consistency)

- Determining a participant's 'musical competency' was also self-reported and whilst the data is consistent (i.e., participants who reported higher competency scored higher on skill tests), if one wants to ensure fair comparisons then other methods of assessment must be required

- The game was only compared to a single practice tool. Although the practice tool used for comparison is a market standard and a popular tool, there are a multitude of other solutions that should be considered for comparison (taking into account gamified practice tools)
- The lack of control due to the environment that participants completed the study potentially led to confounding factors. This also led to inconsistent practice sessions over longer periods of time for some participants. Some participants completed all practice sessions within 5 days where some took up to 7 days and some participants did not complete all practice sessions and conducted the post-test after 7 days since starting their first practice session. This is the trade-off between real-world reflections and the need for control in experimental design. Whilst this is could be considered a limitation; it actually reflects what real-world practice looks like – not all learners have time to practice and major life events will impact this further
- The game itself had issues which led to lower scores for autonomy and usability. This is the unfortunate issue of lack of resources and time able to be committed to development and testing

7.3.6 Future Directions

All of these limitations can be related to one another with two main limitations: a lack of resources and the trade-off of controlled environments for real-world reflection. With additional resources committed to improving the skill tests and implementing additional forms of musical assessment, one could develop a test battery to accurately depict the competence of a learner in regard to a specific skill. Additional resources could also ensure that the game is developed further, with less bugs and more personality, leading to increased engagement and more serious applications within a commercial placement. The lack of control led to self-reporting somewhat ambiguous amounts of time practised, future studies must create a way to determine specific time values which can be reported on a regular basis to the research team. Finally, an issue of both lack of resources and the lack of controlled environment led to inconsistencies with practice sessions over the week period across individual participants. Whilst this does reflect real-world practice and the issue of motivating this particular demographic to consistently practice, one must consider what would be possible if an existing pool of participants or users that fitted this demographic was used for recruitment. The issues faced during recruitment led to a varied range of participants: some were serious and dedicated whilst others may have dropped out and were not worried about completing or particularly invested with the research at all. Conducting

such an experiment in the future should attempt to use existing user groups that have been defined, perhaps more applicable to development and research teams who already have an existing loyal group of users that are most appropriate to reflect the target population. If one were to recruit using such methods and advertise to a large body of potential participants, then the recommendations would be to setup further safeguarding to ensure that bots or auto-fill software is prevented. These techniques include (Skerrett, 2019; Xu et al., 2022):

- Questions that are similar in nature that would yield the same answers from human participation but would vary greatly in responses from a computer
- Timestamping responses and determining the total time taken to complete the survey: if response time seems impossibly quick, it is likely that this is a human response
- Include 'attention questions', which are questions that are unrelated to the study and somewhat absurd; human responses should easily be spotted whereas machine responses may be rather generic
- Include open-ended responses which generate meaningful responses. It was often found that the answers to game-related questions were all unique as participants had varied favourite games and play times; spotting the machine or scripted responses was obvious as they were often repeated or highly generic

Even though these techniques should help prevent scripted or bot responses, it is never completely possible to be void of such a phenomenon. Such responses became obvious through analysis and there was often at least ten responses received within a short period of time and the responses all shared highly similar answers. One must approach analysis of surveys carefully and ensure that these answers are completely removed. Finally, it is important to only offer incentives based on the success of completed surveys or the entire study; offering incentives for simply completing the survey will increase the likelihood of fraudulent responses.

7.4 Chapter Conclusion

This chapter has discussed the improvements to both the methodology of the pilot study and the game, which was based on the feedback from the pilot study itself. The developments to the game were extensive and led to a concept which was highly novel in nature whilst still retaining the key elements of pedagogical value. The study helped to prove that such a novel approach to practice is much more engaging than current methods and can help to increase

specific skills and overall confidence and motivation of learning to play specific instruments. This does not come without limitations, however. The two main limitations that both the study and the research as a whole suffered from was lack of resources and attempting to build robust empirical experimental studies whilst reflecting real-world applications. Furthermore, whilst the skill-tests were validated within this context, they should contain additional assessment criteria or additional tests to help build a robust battery of assessment to a particular skill. Future research should consider the immense work that has been invested to achieve this level of results and how potential stakeholders can support such a journey. With further resources, time and an existing base of users to help test these solutions further, the potential for such novel concepts is limitless and the results from this study should inspire other researchers, teachers or developers to seriously consider how video games can be used to offer meaningful educational value and build skills which have real-world transferability.

Chapter 8

Conclusions

8.1 Chapter Introduction

This chapter presents how each research question was constructed and how the research has helped provide answers to each (i.e., a summary and reflection of the research outputs). This is followed by a discussion of the key limitations that was found through the process of the research; highlighting the specific limitations of the final study and how these limitations reflect on the entire research. Finally, a concluding statement is presented which summarises the main outcomes of the research and offers the larger scale implications of such research, and similar research that have also helped to contribute solutions to the issue presented in the introduction.

8.2 Research Questions and Answers

The current research aimed to identify how video games could be most effective in reducing the high amounts of early drop outs regarding adult music beginners. The central question for this research was:

- **How can video games help to reduce the high early dropout rates which are exhibited by adult, casual and independent beginner keyboardists and pianists?**

The project began directly in placement at the industrial company and there was no concrete direction that could be used as a foundation to build this doctorate upon; it was defined as ‘a blue sky project’. The only tangible goal was that there was a desire to create solutions which would attempt to be the next ‘Guitar Hero’ or ‘Sing Star’, that would make use of the technologies the company had or were developing at the time, which needed to have

serious applications to music learning or creation. The initial question posed above was constructed through the process of consulting literature and initiating conversations with many musicians and potential learners. What was established was that a vast majority of learners wanted to pursue the goal of becoming musicians to some degree but always fell short and would give up on their pursuits rather quickly. The same phenomenon was also observed in other domains of learning where the goal appeared attainable but the process was a huge undertaking and required huge amounts of commitment; specifically, the similarities are most recognisable in context to learning a language. It appeared that learners, particularly adults who were casual about their learning and did not want to pursue tutoring, believed they could reach the goals they had imagined but upon realising the efforts actually required would soon give up – they did not have a passion or enough motivation to continue pursuing their learning efforts. But to what end was the purpose of this pursuit? What became apparent through this process was that all learners, and the majority of all musicians, shared similar goals: the ability to improvise their own songs, play within group settings to a high standard, or create their own pieces; there was a particular desire to play existing musical pieces, as this would demonstrate their abilities most coherently. Furthermore, learning to play others music would open a world of inspirations that would help to feed into learners creative pursuits.

The project initially began with developing solutions that may have helped such learners create their own music in an easy to understand capacity; avoiding complex DAWs and burdening the learner with information that was not entirely relevant to the creation process. The goal was to create a simple yet effective method that would allow learners to express themselves through music without the requirements of the knowledge of the complexities of music and the typical tools used to create entire pieces. These solutions would also make use of new technologies, using VR to create visually striking environments or AR to assist the learners using specific instruments. However, the desires of the stakeholders (the placement company) began to shift, which was also supported by the research this doctorate had undertaken. Such learners could only go so far without any knowledge, skills or understanding of the structure of music and how one typically creates it; this would often lead to repetitive music which would use only a few notes (of course, this was still music, just not what the learners had in mind when they imagined what they could play). Thus, the desire to play other musicians songs became the key pursuit and was the primary goal of this research. At this stage, this goal was focused on using the keyboard, with the specific population being focused not only on casual, adult and independent learners, but also those who were specifically at the beginning stages of learning to play keyboard. This focused direction was a direct consequence of the developments being made at the company at the

time, which was dedicating resources to developing a new style of MIDI keyboard aimed at the consumer market.

Learning to play a piece of music is no small accomplishment and this is where a lot of beginners become frustrated and have a tendency to drop out quickly; the idea of what is possible is unfeasible and when put to practice, these desires are never met and often lead to beginners simply giving up. The emotional reaction of, "I'll just give up" or "I'll never get it so why waste time on even trying", was often reiterated by many of the budding learners that conversations were initiated with. A review of the solutions that had already attempted to solve this issue using gamified learning was conducted. There was a single solution that had taken the 'Guitar Hero' model and applied its purpose for serious application: this was 'Rocksmith'. When reviewing the game, 'Rocksmith' was reviewed extremely well by all musicians and appeared to be a fun way to practice guitar and particular pieces. The reason for such success was related heavily to the instrument itself and how one can learn to play songs using the guitar; not only this, who the game was aimed at also ensured its success. The game was aimed at those who were already serious about learning and wanted a fun outlet which could be utilised throughout their learning journey. Not only this, the idea of becoming a 'Rock God' was appealing and was a common reason for beginners to start their journey of playing a guitar – it was inherently easy to make learning the guitar attractive, when compared to other instruments. Most importantly, learning to read guitar tabs requires far less cognitive demand than sheet music dedicated to the keyboard (or piano) and transcribing guitar tabs to a visual medium was easy to understand and follow on a screen.

Could transcribing musical notation to a visual medium be as easy to understand and effective in regard to playing keyboard? This was the next question the research addressed. Whilst this is not a new area of development (one can see many implementations of this (Julia et al., 2019)), the incorporation of new technologies could help to further such implementations (Raymaekers et al., 2014; Rogers et al., 2014; Trujano et al., 2018; Xiao and Ishii, 2011). Were these solutions actually useful and would they ensure learners can play musical pieces? To some extent, they could but this was only applicable to simple musical pieces or to learners who were already familiar with the pieces; furthermore, learning to play a song by following along can lead to poor form when playing. Although new implementations (*PianoVision*, 2022) considered the use of intonation and hand/finger use for pieces, the more information that is added to such solutions, the further complexity is added, leading to further confusion then frustration and to the emotion of, "This is too hard, I may as well not even try". The issue with these solution is that the learners do not possess the skills which apply to learning to play a piece of music, regardless of how they pursue learning them. Beginners can learn the knowledge or pursue a specific path of learning but need a foundation of skills

to bolster their pursuits and ensure regular time is committed, leading to less disinterest and eventual drop out.

The market place solutions took the form of learning applications in one way or another. These solutions were almost identical to one another but specific designs and learning paths ensured they were unique in some way - even offering lessons by famous musicians. Whilst these solutions were not new, as they were derived from the CD based style of learning, their use of mobile applications and gamification ensured that this style of learning had been revamped for the new generations of learners. By pure statistics, it was clear that these applications were popular, often gaining hundreds of thousands of downloads, even millions. But the issue still persisted as users would download them, use them for a week or so, before completely abandoning their journeys entirely. What the applications were offering through marketing was a way for beginners to become the musicians they desired to be whilst also play pieces of music fluently, all whilst having fun and wanting to learn. This motivational pull was most often in the form of gamification which typically was considered an afterthought of the development process. Whilst these applications would help those that were already serious and capture a small audience, the promises of becoming competent musicians with gamification being considered an afterthought, often led to users dropping out quickly and becoming demotivated to learn at all. This phenomenon is not only apparent in learning music but any domain in which a vast amount of people wish to learn: languages, exercise and even meditation practice are being 'gamified'. This concept of gamifying learning was not in the pursuit to motivate learners and offer meaningful practice, but an attempt to market to a mass audience and ensure retention of a large user base.

There are a multitude of learners who want to play a piece of music and there are many reasons for dropping out. Yet it seems the most common reason is lack of commitment and a lack of passion to continue. If all learners required some form of gamified motivation then there would be no musicians at all; the time and commitment that is required to become such a competent musician is the very reason those who listen to music appreciate it. However, the unfortunate truth is that a vast majority of musicians who are talented have had at least some exposure in their lives with music and is ingrained within them throughout life. The adults that this research was focusing on did not have such exposure or experience with music and as such the process of learning was more substantial and difficult. The same is of course true for learning a language, as almost every single person speaks a language fluently but never actually engaged with learning to the extent adults do. This is where the true frustration and reason for the extreme number of adults dropping out stems from. The lack of these fundamental skills and exposure in conjunction with the high amounts of time and effort required to achieve something meaningful will naturally lead to frustration

and a desire to pursue activities which are easier to the learner. If such learners wish to continue their learning, they require a foundation of skills to build upon and use to progress through the learning journey. These skills are outlined in the literature review and, through the doctorate, a particular skill was chosen to develop video games for: the skill of reading musical notation.

The solutions reviewed offered temporary fixes to an issue that extends over much greater periods of time; there were few considerations into how to ensure the longevity of a learner. Thus, the research concluded that the most effective use of video games in this capacity would be to act as supporting aids. These aids would help beginners build foundational skills which in turn ensures the learning process is more approachable, less frustrating and builds positive association with learning. This eventually leads to the longevity of learners journey. There were some applications in the literature and the marketplace that were focused on building gamified tools for training specific skills. However, these solutions were once again considering gamification as an afterthought and never considering the use of game-based learning. Why had no solution considered building games for the purposes of serious learning in context to keyboard? Thus, this led to the novel solutions developed in this research in an attempt to progress the field of music learning using gamified methods. The assumption was that a video game would of course elicit higher amounts of engagement than a simple gamified training tool; with the eventual goal to replace learners recreational activities with such practice games, that could offer the building of transferable skills to real-world applications. However, this led to understanding what such a concept would look like and if such a video game was developed, could it help to acquire or improve a specific skill and could this have real-world applications. Finally, how one assess such criteria must also be explored; the literature review found that many of the solutions were assessed in short time periods and did not consider the transferability of their learning to real-world applications. The specific question that emerged from this stage of the research was summarised as:

- **Can adult, casual and independent beginner keyboardists passively acquire or improve specific skills, which typically requires rote learning and have meaningful real-world application, through playing video games?**

At this stage of the research, the LUMI keyboard and companion learning application (*LUMI*, 2020) was in production development and the researcher was working alongside the software development team with the goal to produce mini games that would work alongside or within the learning application. The learning application would offer a gamified approach to learning musical pieces but the novel combination of this with game-based learning or practice would help to ensure that the company had a unique perspective when compared to other consumer

based software and hardware solutions. The game-based solutions were initially developed as a suite of mini games that would target specific skillsets which were fundamental to increasing the quality of learning and playing; the goal was to ensure that learners felt motivated to return to practice and would not drop out so quickly.

A host of mini games were created and the ideas were never in short supply, however, the research lacked any specificity and direction for how to develop effective solutions and how one can assess them. In the pursuit of solving this, a group of mini games was developed which would be used in a small scale study. Drawing upon many areas of learning games, as well as some mobile games, the developed games were unique in comparison to those found on the marketplace and in the literature. The initial study helped to provide primary research into the issue that had been established whilst also highlighting that such a solution was deemed novel and could be highly viable – this was not only ensured by the target population but by learners of various skill levels as well as music teachers. For the sake of establishing a research position, the study was worthwhile. However, the study had many limitations: the measurements of engagement, usability and pedagogical value were all qualitative and were not empirical in any sense. Not only this, the games that had been developed were still not living up to the original expectations of what learning-based game could be; they were not a complete overhaul of the architecture but more gamified training tools. To pursue remedies to such limitations, further specificity was required. This led to the second round of development in which additional prototypes were developed with a specific skillset in mind: the skill of reading musical notation. Developing such games proved difficult as there was no design considerations of development frameworks to particularly adhere to. Through the process of design and development, a framework began to form; this framework would be imperative for future developments and would provide the process of iterative game development that would help lead to the final game.

Going forward, games that had been reviewed most positively and could offer pedagogical value (i.e., improve the skill of reading musical notation) during the first study were developed further, whilst additional concepts were explored and developed. Particular attention was paid to how these concepts were designed and the development process was well documented; this would be useful in developing future concepts and to other researchers within this field. Each game that had been developed was placed in a specific category to help structure the plethora of prototypes that had been developed at this stage. These categories also helped to create a spectrum of how much a practice tool could resemble a video game. Through the second study, the goal was to determine how far these prototypes could become video games whilst still retain some pedagogical value. Various concepts were developed and two particular games stood out: Staff Arcade and Music Graveyard. These concepts were far from what was

found in the literature and began to shed light on how to develop learning-based games in this regard. Through reviewing relevant literature, specific assessments were used in the study to help gauge the engagement and usability of each prototype. The study showed that these assessment methods were useful but further reviews were required and additional assessments must be provided to help assess usability and pedagogical value in an empirical fashion. From this point, the decision to take the single prototype that resembled a video game the most forward was difficult; it would have been ideal to develop the other prototypes further but lack of resources prevented it. Therefore, Music Graveyard – the RPG style learning game, was developed further and assessment methods were designed in line with those found in the literature to help develop a robust and empirical method of assessing concepts which are typically reviewed using qualitative and unstandardised means. At this stage of the research, the framework for design and development was significant, the prototypes were novel but the assessment methods were still lacking and the game needed to be proved effective for real-world applications.

The last portion of the research was composed of two rounds of development and two studies. The first round of development was solely focused on the improvement and extension of the RPG style game, which was now being dubbed, 'The Crypt of Notation'. It was at this stage that the potential for this style of learning and practice was realised as the research had finally reached a point in which the concepts were no longer gamified training tools but were learning-based games; perhaps even more than this, they were games that could be played without the sole intention of practice but for the purposes of entertainment. However, the assessment models for the three main criteria (engagement, usability and pedagogical value) were still weak and the model needed to be applied to real-world scenarios. The pilot study was used to determine the effectiveness and discover weaknesses of both the game and the newly established assessment method. This stage of the research begun to answer the secondary question. The assessment methods used were indeed robust and with some tweaking: standardisation and increasing reliability of particular questionnaires regarding usability and engagement by incorporating further literature, the game could be tested in real world scenarios. Improving upon the key limitations of the pilot study, a final study begun to take place. The final study was based on the pilot study but used custom tests of reading musical notation abilities and extended all questionnaires to ensure that the measure of engagement and usability would be accurate and replicable. As the study took place within home environments of learners, the time played would be a direct indication of how engaging the developed game would be. Results clearly showed that such a concept does indeed yield higher amounts of practice and in conjunction with the novel practice setting, this leads to a dramatic increase in the acquisition and application of the skill of reading musical notation.

Can a game passively improve or help to acquire a skill which has meaningful application to the interest of this research's population? The final study proves that it can, and future research should utilise the design and development framework as well as use the assessment methods laid out to strengthen this point further. However, there were some limitations of the final study which reflect the majority of limitations of the entire research; whilst they are significant, future research can build upon this and continue to build upon this distinct approach to gamified learning in the context of musical learning.

8.3 Key Limitations

This research explored how video games could be most effective in solving the issue of the high number of adult beginners dropping out early from their music learning journeys, particularly focusing on those who learn to play keyboard. Through the course of the research, the limitations of both the developed solutions and the methods of assessment had been improved. The lack of specificity and empiricism often led to interesting games but a poor method of assessing them. Through multiple studies, an assessment method was defined in which the goal was to measure the acquisition of a particular skill and the real-world application of such a skill. The pilot study (study three) helped to build a model of assessment which could measure the opinions of engagement and usability in a reliable and valid way. The final study helped to prove this within a real world context, ensuring that the concepts of engagement and pedagogical value (i.e., acquisition and application of a skill) could be quantitatively measured in real-world settings. However, there were limitations to the study which must be considered going forward. The two overriding limitations can be summarised as follows:

- **A lack of resources in regard to development of the game and assessment tools as well a lack of an existing user base**
- **The balance of a controlled environment whilst trying to reflect real-world applications**

Feedback for the game highlighted key bugs that were not detrimental to the gameplay but certainly hinder the overall engagement. The lack of time and resources that stem from a single developer attempting to develop such a large scale game which is playable on multiple platforms and machines, whilst simultaneously conducting research activities. There are two schools of thoughts in this regard. The limitation could be seen as the choice of game that was developed for the final studies or the lack of support and resources available at the time.

Development of an RPG style game is no small feat and developers must design artwork, mechanics, complex menu systems and ensure that all the parts are working in unison. This complexity did indeed lead to a lot of time being dedicated to development and whilst a novel and enjoyable game was produced, one must consider what other genre of game may have been more optimal. As mentioned, the consideration to pursue the more arcade style of game was the other option after the second study was conducted. Could choosing this style game led to a game which was completely bug free and ensured more time was spent on the assessment tools? It is possible but this also would have led to a solution which was less of a video game and more of a gamified practice tool; the game would have required vast amounts of design and artwork to actually ensure high amounts of engagement (whereas the RPG focused on the individual mechanics) and such talent was not available. So the limitation is more likely due to the lack of resources and support at the time. Regardless of the choice of game that was taken forward, with a small team comprised of designers and additional developers, the potential for any of these games would be immense; it is unfortunate that the researcher was not able to find collaborators or find the support from stakeholders but going forward perhaps other researchers or developers can assist in this pursuit.

Additional resources would also be useful in helping to build a more robust method of assessing a learners abilities with a particular skill. As mentioned in chapter 7, the ideal solution to this limitation is to build a battery of tests that would specifically measure the skill of reading musical notation (with the extension to other skillsets). Whilst the skill tests that were developed for the final study were certainly reliable and valid, they have significant room for improvement and it is only due to lack of resources this envisioned goal was never fully accomplished. This limitation of lack of resources is not just applicable to time and the size of the research and development team, but also to the user base available. As covered in chapter 7, recruiting such a large number of participants to participate in highly extensive study proved tricky. Most participants in the study all showed great initiative and were extremely viable candidates, but finding these participants was not easy. This result shows that there are particular users that are ideal for this research and recruitment would have been a lot easier with an existing user base to advertise to. The placement company's mailing lists were useful in this regard, but a lot of users were from the prosumer groups, rather than the consumer ones; as a result, they were either uninterested in learning concepts they already knew or were simply not the right fit for the demographic. There is serious thought into how successful such a study would be if it was conducted by stakeholders who had a large user base of the particular population in mind; there are certainly user bases out there but these are typically 'professional user testers' and access to such method of recruitment will, once again, require substantial resources. The idea of this research and the solutions that have

been developed are worth merit but do require further time and resources to ensure their success; it is the hope of the researcher that other stakeholders and research bodies will help to support this success.

The second overriding limitation, the balance of controlled environments and reflections of real-world applications was constant through the research. The pursuit of attempting to quantify and build empirical methods in a field of research which is typically dominated by qualitative research proved tricky, but was never abandoned. Most of the research in the field was either interested in assessing musical abilities or building solutions to improve musical abilities. Authors who were developing solutions typically assessed their prototypes with interviews or questionnaires, rarely considering how others could utilise their assessment methods nor how reliable they were; there was a lack of empirical research in this regard, hence the desire to pursue such a goal. Whilst the final study is mostly quantitative in nature, there are still significant questions which participants answered based on their own interpretations. How long they practised for, how confident they felt reading music and all questions relating to usability were opinions. The desire for empirical science whilst also attempting to measure such concepts in real-world settings led to confounding factors. As observed in the final study, the variation in the practice session competition was significant and not all participants completed the study in the intended manner. Of course, this does reflect the real-world complexity of learning and practising but does also reduce the merit of the study. The solution to such a complex problem is not simple but does relate back to the primary overriding limitation of lack of resources. With the correct user groups, these issues would be less so as such users would undertake the study in a much more serious capacity. Not only this, but additional developments could ensure specific measurements of practice time and a robust method of assessing ones musical abilities that would not require self-reporting by the participant.

The final limitation that became apparent from the final study was the comparative tools used. The studies only concerned themselves with one tool to compare against. Ideally, with a large user base there could be multiple control groups to compare the game against and each group would use a slightly more gamified solution. However, the need for a comparison group at all could be questioned. The fact that the game group significantly improved from pre to post in all categories is a worthwhile result and perhaps the limitation of multiple comparative solutions indicates the need for longer studies to be conducted. Whilst the study was conducted over a period of a week, this is still a short amount of time (although, longer than most studies found in the literature). This limitation is once again due to lack of resources and a lack of access to the correct user groups. The question one must consider is how long is enough? When the research initially begun, the idea was to run studies for a

much longer period of time than a week, ideally for months, if not a year. This long period of time would reflect the longevity of a learner more accurately and would clearly show whether this novel method of practice would be effective in reducing the drop out rates of adult beginner keyboardists. Unfortunately, within this research, this was never attainable; the author offers cautious optimism that running such studies would yield results that prove these learning-based games do provide a much more positive practice and would lead to increased motivation and less amounts of drop outs.

8.4 Concluding Statement

The developed games have helped to answer both research questions. Through the initial phases of the research, the discovery that learning-based games would be most effective in helping to reduce the high number of beginners dropping out early from their learning was immensely impactful. Existing solutions had either tried to replace methods of learning to play a song with digital technology or creating new hardware solutions; these were novel and interesting but offered no transferability to entire process of learning and were not impactful in solving the complex issue of this research. Other solutions were an attempt to replace the entire learning journey of the learner and were rehashing old ideas that existed on CD based mediums (i.e., learning applications). Solutions found in literature and the commercial world that were designed to help learners practice specific skillsets were not considering the use of game-based learning and in all contexts the implementation of gamification was deemed an afterthought. As such, this research proposed a distinct and novel approach to the issue in which a series of learning-based games were developed, to significant degrees of success. The games could certainly be improved upon and the assessment methods require further development and critiquing before considering their use within longitudinal studies. The process of designing learning games in the context of music was not easy as there was a lack of documentation and frameworks that one could adhere to; this was also related to assessment of such concepts particularly concerning their real-world applications. The secondary goal of the research was to develop a framework of design and development whilst also building a robust method of assessment which other researchers could use to build their own learning-based games. Whilst this goal was certainly achieved there are serious considerations for the future of this research and how to ensure that these concepts have an impact on such learners over prolonged periods of time The future goal would be to have a suite of these games which are developed using the framework and used in a longitudinal study to assess their ability to reduce the high amounts of drop outs exhibited by adult beginner keyboardists (using the assessment methods develop through this research). It is

presumed that these games would have serious impacts on the longevity and motivation of learning regarding adult beginner keyboardists, based on the findings of the studies that have been conducted through this doctorate; this research therefore has significant and worthwhile merit.

There exists a huge numbers of adults that have a desire to play keyboard in a casual capacity and reach a level of competency they can feel proud of. In an ever growing digital technological savvy society that is full of short bursts of attention and immediate gratification, the current use of gamification in music learning and the outdated learning-based games are not sufficient to capture the attention of beginners for extended periods of time. Marketing strategies will try to sway such adults to use solutions which offer a pathway to becoming a music prodigy within an incredibly short time; this is unrealistic and adults will often feel demotivated when they never reach the skill level they were promised. Thus, if such a solution that could elicit the entertainment values of a video game whilst ensuring learners passively acquire or improve skills during the process, this would likely lead to increased practice rates and increase longevity of beginners learning journeys. Such concepts help to build positive associations with learning, increase motivation and ensure adults never completely drop out from their learning. This research has proven this to be true on a small scale but future research must consider how additional resources can develop such solutions and assessment methods to prove this is the case over much longer periods of time. It is to the knowledge of the author that no solution has attempted to use game-based learning in this capacity and that the development of these novel games is both significant and original. The implications this research offers are far greater and applies not only to beginner keyboard learning but also other skill levels, instruments and areas of learning that are desirable but require serious commitments, particularly language learning. Finally, the hope of this research is to not only inspire learners to practice more often but to help learners realise that learning is innately fun, especially when the pursuit of such learning is so creative in nature.

Chapter 9

Considerations and Future Recommendations

As stated, the three original and significant contributions were the novel artifacts that were the learning-based games, the novel assessment method created and the framework of design and development that other researchers can use to ensure their pursuits in developing learning-based games have focus and are as smooth as possible; the repository of the code can also help expediate the entire development process. Whilst the framework and overall development cycle is highlighted throughout the thesis, it was important to distil the main points into a concise and easy to digest format. This chapter is composed of two sections: the first section is broken down into three subsections of considerations useful for: designing, developing and the assessment of learning-based musical games. The final sections presents the future recommendations that future researchers should consider when reviewing this work. The recommendations are based on further developments of the game and assessment methods as well as future directions on from a wider perspective, with consideration to the main issue this research proposed from the beginning.

9.1 Design Principles

Through developing a large array of new video games and practice tools, a lot of valuable information was gained that is believed to be useful for other researchers and developers regarding design considerations for gamified practice and learning. Whilst this information is most useful and pertains to music and keyboard learning, the lessons can be applied to any area of learning which shares similarities, most notably, learning any other instrument

or a language. A set of design considerations which one should consider when developing musical practice games is listed as follows:

- Ensure an iterative flow of development and testing is adopted, focusing on testing regularly which has a clear aim and correct participant demographics. This cycle of development and testing was key to this research developing novel learning games; whilst the design of new ideas was never short, testing would always lead to unexpected insights and help further the research. If the focus were on design and development then the games developed would have been far less reflective of the needs of the learners and as such had a less significant meaningful applications

- Hold consistent meetings with designers and developers. The meetings that were held were intended to be free of judgement, allowing freedom to express ideas to any degree. Furthermore, one should seek advice and insights outside of the development team, this process allowed the research to consider ideas which were not from the perspective of a game developer, but the player themselves

- Consider other areas of inspiration besides the one you are developing for – go beyond this and look to areas which are not solely based on video games for further inspiration – going outside the box will lead to novel ideas. As discussed throughout the thesis, there were a number of inspirations and it was typically from reviewing games that one would not consider applicable to the solution that the most novel and effective ideas were generated

- Design concepts with a lot of choices and observe play sessions to understand which choices are most impactful. Through the design process, there were a huge number of ideas and smaller concepts that were imbedded into each of the games. Through testing sessions, some choices were not used at all whilst some were the sole focus of the play session; without developing multiple choices, there was no way to understand which mechanic or design would yield the most engagement or enjoyment

- Try not to force any play style or assume a game will be played in a certain way: open ended interpretations are crucial and lead to the most valuable knowledge. This point was learned throughout the research, as it consistently discovered that the games would be played in a certain way and mechanics were designed to cater to this. However, through play testing sessions, these play styles were not adopted and each player would use mechanics in their own way. The ideal option was to develop a set of mechanics and rules within a game environment and allow players to define their own styles (their meta games) which led to increased personal investment and depth to the games

- Users want progression more than they want to beat their high sores; whilst mobile games focus on the infinite high scores, this does not equal longevity – ensuring your game has a reason for others to return which is not just beating a previous score, leads to personal investment and a greater return rate (this was most apparent when players were seeking to complete multiple missions in the RPG style game and wanted to return to the game simply to complete them)

- Tutorials cannot be a single instance and must be reiterated throughout the process. Whilst it is important to show how each game works during the beginning of the game, certain mechanics may not be obvious to players and this must be highlighted throughout the game. Not only this, but a tutorial must also be 'hands-on' and not just reading text; the application of what a player has learned ensures they will retain this information. It is important to develop tutorials as the game is developed, do not leave this until last

- Lay out all the attributes you wish to include in your development and use a MoSCoW (Spiru et al., 2019) or similar method to ensure that the most important ones are always included; a solid plan before beginning is crucial to ensuring that development does not get overly complex. It is important to not add attributes because they may be perceived as interesting - always ensure there is a reason for adding them and don't waste time on developing things which will never be used

- Understand that certain mechanics may never be as useful in your design when put into practice; don't get hung up on this – remember you are developing for others, not yourself

- Menu system and UI design needs to be simple but still have strong feedback – simple things such as button click sounds and background music help to separate a low quality game from high a quality one

- Plainly and succinctly state your goals for your intended prototypes – if developing for a specific goal does not work then move to another one and try not to defend an idea if you truly don't believe it has merit

- Do not attempt to replace an entire system of learning, it is better to try and use gamification to aid learning, rather than trying to set unrealistic standards

- When building educational concepts, only have a few educational goals in mind and consider how other mechanics can improve other areas

- Do not just use new technology because its novel – have a meaningful approach which will build on retention rather than trying to stand out

9.2 Development Principles

This subsection shares the key lessons that were found through the development of musical learning games. The key principles and pitfalls one should consider when developing such games, and the main applications and use cases for the code repositories one should find most useful are listed:

- Avoid over developing the mechanics and, most importantly, the design of game – if you can ensure the most simplified version of your game is engaging then adding more to this will make it even more engaging. If using a model such as MoSCoW, then stick to this as close as possible but remember that plans will change during the course of development – being flexible and ensuring that a plan is followed is an important balance

- Setup a system which can be called upon to avoid repeating yourself per prototype by using generic functions and assets which can be used on many prototypes – this also applies to design elements too including UI; particularly studying SOLID (Kexugit, 2014) principles when using object orientated programming

- Use other people's work, especially when prototyping and you want the players to understand the full picture –this helps avoid spending too much time on creating assets or figuring out complex ideas

- Setup source control from the beginning of the development process and keep your project tidy. This will help during testing – there were multiple instances where an older mechanic or design paradigm was preferred and as source control was in place, it was easy to revert these changes. Furthermore, source control allows collaboration and others to create their own instances of your project – this can help with development times and allows others to demonstrate their ideas visually

9.2.1 Available Code Use Cases

- Whilst the project used a third party plugin to aid connections with MIDI devices, this was extended using custom listeners. A class can be found which handles various inputs and outputs based on MIDI devices and can be used to help other researchers

setup MIDI connections within their own games and make the process of connecting the events of the MIDI device to practically any action. The implementation uses the event systems and is contained within a namespace whilst also being static. This ensures that developers do not need to have an instance to the script in every other script that may use MIDI but simply call the static event every time they wish to connect a MIDI action to a mechanic. The event also takes into account 'pressure' of the key pressed which could be used to carry out mechanics which may not want players to fully press keys in (such as puzzles)

- A simple rhythm clock class is included which gives developers access to specific public variables that can be changed within the unity editor and ensures that the accuracy of rhythm is not dependent on framerate. This is a great for ensuring mechanics can be synchronised with rhythm or particular animations or movements

- A system which can generate notes within a given scale is also provided. Developers can implement a public class which other scripts can call upon if the use of scales within their games is desirable. For the sake of ease, the public class uses strings (i.e., the names of scales) rather than the numerical values. Developers can choose a particular scale, and a series of notes is generated based on that scale; additional methods include choosing a random note from that scale or even generating random but musically pleasing patterns. The system takes into account both sharps and flats and can even generate accidental notes; future implementations will also generate chords and satisfying chord patterns (following music theory principles)

- Generating simple but effective music based on a set of notes. The procedurally generated music found within the games throughout the research was generated by a class that takes a series of notes inputted by either developer or user and generates a melody. Whilst the implementation of this used Audiohelm (*Audio Helm for Unity*, 2014), this implementation is not restricted to this and can use any sample or sound file that the developer wishes

- The ability to 'draw' or generate notation and letter representations from a series of notes. The most basic use case of this is to input a series of notes and allow the system to choose a random letter (or sprite, object - whatever is desirable) and display this to screen. This was extended to allow developers to set a starting position (i.e., the lowest note from the series of notes they are using in their own games) and set specific positions on a musical staff. For example, one could either use the staff sprites provided, or their own, state that the lowest note will be 'middle C' and that the system

uses a total of 5 notes. The class will generate logical positions that notation could appear on the staff for; a random note is chosen and the notation is displayed on the staff at the correct position of that note. This is extended further by inputting a total of notes that wish to be spawned and the class will generate horizontal positions and output a random series of notes and consequential notation on the staff. This is essentially a foundation to build musical games focused on the musical staff (such as those found in Staff Arcade and Notes Invaders)

9.3 Assessment Principles

Finally, what is believed to be the most important lessons to take into account when designing and developing assessment methods for gamified practice tools/games are shared. It is believed that if these points were known earlier in the research, significant time could have been spent on developing tools which yielded further meaningful application as well on studies which had additional focus (i.e., more resources spent on the development process rather than understanding how to approach the process). It is the hope of the author that by following these lessons, one can expediate the process and focus on what is most important. Below is a list of key lessons learned:

- Plainly state your participant demographic and stick to this as closely as possible – use the means you have around you and try to avoid opening to the major public too early on; do keep in mind that extending play testing outside of the development team is still crucial
- Do not be afraid to show your work and ensure you test and get feedback as much as possible – you will tunnel yourself in if you don't do this. This was the case during the first development cycle of the research in which it was eventually learned that such novel prototypes required feedback from other perspectives
- Don't be afraid of quantitative methodologies – this leads to more objective and empirical science which is highly replicable. Whilst qualitative research is still highly viable and is required, one should consider how empirical and replicable the research and methodologies can be. This field of research leans to qualitative or mixed methods but if one wants to attain a high standard of reliability and validity then pursue a more empirical route

- Ensure you refer closely to literature for similar assessment models as this helps validate your work and gives a strong direction. This was later discovered in the research and was pivotal to building assessment methods that were focused and robust
- Avoid overly subjective questions which lack meaning such as 'fun' or emotional responses as this is hard to validate and will vary from person to person – try to measure these items using more observational or quantitative techniques; this also requires using existing methods of assessment that have already been validated, one should build on others research in this regard
- If you are asking quite open-ended questions or specific ones, ensure the participant knows what you are referring to – if you observe a lot of mid-point scale answers this does typically mean they had no opinion but that they did not fully understand the question posed
- Test on specific items rather than general; you know your game is quite fun by the initial reaction but what specific items ensure its' enjoyment; particular mechanics or designs? This was specifically explored in chapter 4 in which particular choices were posed to the participants to determine the exact mechanics and designs that led to increased engagement

9.4 Future Recommendations

Recommendations for future research in the development of the learning-based games and the assessment models of such games, as well as the applications of both are presented below. The larger implications and distinct avenues that this research may also take are also presented in which future researchers may consider. Whilst these 'big picture' applications are not entirely related to the research directly, the author proposes that with the knowledge this thesis contains, one could pursue other avenues to solve the original issue stated, that of reducing the drop out rates exhibited by beginner musicians.

9.4.1 Recommendations to Further Develop the Learning-Based Games

Recommendations to improve the RPG style game, 'The Crypt of Notation' which features in Chapters 5, 6 and 7 are presented below. This includes specific bugs that were found, key design and mechanical changes. Some of these changes are applicable to development of additional music learning-based games.

- It is recommended that particular sounds relating to the rhythm aspects of the game are more precise. Specifically, the sounds that relate to when a key is pressed and the sounds that are played on the beat of the tempo. It was found throughout the development of each game that whilst one could ensure high accuracy regarding the rhythm and this was reflected well through visuals, the sound aspects were never quite synchronised. This is not an issue with the system that determines rhythm but the sounds themselves. This is an issue that stems from not creating sounds specifically for the game but relying on those found on the web. The problem was determined when analysing the sound files themselves: there were often small gaps before or after the sound was produced, but was required was for the sound to be played immediately, without delay. Therefore, when playing a sound, this delay would cause a disconnect between the visual rhythm components and the sound; one must either design their own sounds which have no delay or analyse the sounds found online closely and edit them if this issue is persistent

- Another frustration conveyed by participants which not only related to 'The Crypt of Notation' but to all other games (and even the comparison practice tool) was a lack of tutorial in setting up the MIDI controller before the play sessions began. This would often lead to participants feeling confused when they were playing the correct notes but were receiving incorrect feedback; this was typically due to the keyboard being in the wrong octave. Whilst the majority of solutions developed did have a menu to assist in the setup of this, this was often found in sub menus and was never shown directly during tutorial phases. Future games must ensure that a setup menu is displayed on first play and the players are shown how to access this, with access being easier to understand

- Specifically to 'The Crypt of Notation', a design issue was found in regard to notation objects overlapping one another; this often led to confusion for players in determining which notation they were actually playing and caused frustration and a lower play time. This issue was also consistent with the feedback from play sessions of the other training games. Participants would state that the notation was not quite in the exact location or that the notes were too small on the staff, adding to their confusion which particularly frustrating for beginners. Future developments should take this into account and ensure that if notes are generated at run time, their positions are accurate and the sprites used are large and readable (requiring substantial play testing of a wide range of players). Specifically for 'The Crypt of Notation', all objects that had some form of notation and were visible on the screen were shown. Future developments will adjust this and set a

specific radius to the player of what notations can be shown and ensure the spawning of notation objects are far enough part that the overlapping issue is remedied

- It was found that the puzzles in 'The Crypt of Notation' were described as repetitive and had a lack of variation or relation to the game. This feedback also highlights the need for all mechanics in games to offer some meaning to the rest of the game and fit coherently into the overarching core loops. For the game specifically, the puzzles should relate to more meaningful progression such as unlocking doors or gaining additional rewards rather than being required to progress completely. Furthermore, these puzzles need to be more varied and contain additional concepts that are not just shuffling items into a correct order. This applies to all other game development: if a mechanic or design does not fit into the ethos or add meaningful progression to the overall game, it may not be worthwhile to include. Going forward, the puzzles will be developed further to increase variation and additional concepts will be explored to add further depth and help to tie this with the overall narrative and progression of the game
- A final future recommendation is to consider how content is generated for such games. For most of the games, levels and progression was procedurally generated in an exponential progressive manner (using the 'saw-tooth' model of difficulty (Holleman, 2019)). Whilst this style of development ensured that a lot of content could be developed, it often led to a feeling of repetition and a lack of overall depth to each game. Feedback from the final study highlighted that the initial phase of the game was highly enjoyable and participants thoroughly enjoyed the hand-created levels but often felt the other levels were rather repetitive in nature. Although developing each level by hand and ensuring that all mechanics, sounds and visuals match is a much longer process and is most suitable for those who can dedicate their time solely to this ambition or work with a team, one must consider the trade off between large amounts of content which lacks variation with a smaller amount of content that has a vast amount of depth and personalisation – helping to further capture the attention of players

9.4.2 Recommendations to Further Develop the Assessment Methods

Recommendations to further the developed assessment methods that were constructed over the course of the research are now presented. These recommendations include building a battery of tests to further measure learners musical capabilities, how one considers measuring practice time on a specific scale, and building a more robust methodology which still reflects the real-world measures and controls confounding factors with more stability. With such

recommendations, the implication is that these assessments should be used in longitudinal studies over much longer periods of time to further assess the ability of such games in the lives of the independent, adult learners that this research targets; helping to prove that this novel method of practice will lead to longevity of learning.

- It is recommended that a series of tests are developed which can be used to further assess a leaners ability to read musical notation (or the skill that one is attempting to develop game-based solutions for). Whilst the final study proved that the testing methods were appropriate and reliable, this reliability needs to be increased to ensure that these tests can be used in an empirical fashion over longer periods of time. It is recommended that researchers consult other methods of assessment and look particularly to the domain of psychology for these tests if they wish to pursue a more quantitative approach to their testing. This development will help satisfy the two limitations found from the final study: the average reliability of both tests and the self-reporting of the participants competence of playing the keyboard and reading musical notation. With further developments of both tests, one could determine for definite the skill that a learner possess and their musical competence; this would help increase the validity of tests whilst ensuring they are reliable when used in long term testing practices

- It is recommended that self-reporting how long a participant plays for is not pursued and that using telemetric data is preferred. Implementing such facets is not a hugely large undertaking when using development tools such as Unity; in fact, there was work conducted into tracking telemetric data of the participants play experiences. However, this was not used in the final study as capturing this data in the comparison practice tool was not possible and would lead to unequal comparisons. Going forward, one should incorporate this and ensure that if any comparative tools are used, they too capture this data, leading to specific time frames which can offer more specific quantitative analysis

- It is recommended that specific activities are also recorded using telemetric data. Understanding exactly what the participant was participating in when playing the game would have led to a deeper understanding on specific mechanics that were most engaging and further developments would focus on this. Future researchers should consider how they can track such data and what data is most important. For example, in ‘The Crypt of Notation’, it would be imperative to know how much the cosmetics were used, what items were purchased and how often the arena was used

- It is recommended that if one wishes to pursue recruiting a large array of participants through contacting a large public audience, particular care is given to safeguarding any surveys or participation in the form of questionnaires. As discussed in chapter 7, even with safeguarding in place there was still a significant number of responses that were either scripted using software or filled out by bots. This occurred regardless of stating the incentives would only be offered on competition of the entire study (a whole week of participation) so one can only imagine the larger numbers of fraudulent data would have surfaced if incentives were given on competition of the initial questionnaire. There are particular guidelines that one should follow which have been described in the limitation section of chapter 7 but it should also be noted that if an existing body of users existed or 'professional' testers were used, this issue would also be negated. There is particular literature and frameworks that have been developed that future researchers should also consider reviewing before conducting any questionnaires that are advertised to a large public audience, such as the REAL framework (Lawlor et al., 2021)

9.4.3 The Bigger Picture

The above recommendations are directly related to the games developed within this research and relate to the methods of assessments that have been developed over the course of multiple studies. Considering the main question that this research originally proposed, there were other research directions and solutions that one could also consider. It is recommended that these directions are pursued whilst using the assessment methods that have been developed as these methods have been proven to be effective at measuring improvements of musical abilities within real world settings, the usability, engagement through custom questionnaires and measuring specific practice rates. These recommendations include the other games that could have been developed and how other researchers could pursue distinct genres, the incorporation of new technology that has improved over the course of this research as well how to implement AI and machine learning techniques that have also been improved during the doctorate.

- It is recommended that researchers review the games that have been discussed in prior studies within this research and consider the other genres that may also be appropriate for learning-based games. Specifically, the concepts that were focused on arcade style and the combination of 'Staff Arcade' and 'Notes Invaders' was of particular interest. A full list of prototypes that were designed (in which not all were developed), is made available at the link found in chapter 1. These prototypes all had merit but due

the limitation of time and resource constraints, were never fully developed and their potential was never realised. Using the framework that this research has constructed; other researchers could develop such concepts in a much shorter time frame and it is the hope that additional resources will be provided to explore such concepts further. There was never a lack of ideas once the research had established the gap in knowledge of a lack of learning-based games and this research only scratches the surface of the potential games that could be developed

- When exploring potential solutions during the early stages of the doctorate, a review of the literature specifically explored the use of new technology. What was required at the time was a robust method of tracking hands within a virtual or augmented reality. The technology was simply not sophisticated enough to handle the desires of the envisioned prototypes and hand tracking technology was rudimentary as well as being extremely bulky, requiring expensive setups. During the course of the research, the technology has improved and VR and AR headsets are now developed with internal hand tracking, making the development of such learning-based games with new technologies more appropriate. Furthermore, there has been advancements in feedback using AR and AR technology, typically in the form of haptic gloves. These advancements can also help to remedy the other key limitation found at the time, a lack of feedback which is required when learning physical devices. It is recommended that researchers seriously consider the use of such technologies going forward

- It is recommended that future researchers begin to explore how AI and machine learning can be incorporated into music learning. Whilst existing solutions that attempt to use AI in their learning systems are rather basic, often determining what notes were misplayed or showing easier exercises if learners continue to struggle on more advanced ones, there is an avenue yet to be explored. The combination of hand tracking (using new technologies) and AI to determine exactly why learners may struggle on either playing a piece of music or how they perform in a game. The concepts that could be developed would advance the field of music learning and begin to replace the traditional style of human tutoring with computer aided ones. Whilst this is a huge undertaking and a rather understudied field, there are emerging solutions to this end (*Gemini - Ultraleap documentation*, 2021; Musy, 2022; Wee and Mariappan, 2017)

References

(n.d.), Technical report.
URL: *https://musiccreativity.org/*

About Music Learning Theory – GIML – The Gordon Institute for Music Learning (n.d.).
URL: *https://giml.org/mlt/about/*

About the Suzuki Method (n.d.).
URL: *https://suzukiassociation.org/about/suzuki-method/*

ABRSM (2018).
URL: *https://gb.abrsm.org/en/making-music/preface/*

ABRSM: (n.d.).
URL: *https://gb.abrsm.org/en/exam-support/apps-and-practice-tools/sight-reading-trainer/*

A casual revolution: reinventing video games and their players (2010), *Choice Reviews Online* **47**(12), 47–6689–47–6689.
URL: *http://choicereviews.org/review/10.5860/CHOICE.47-6689*

A Dance of Fire and Ice (2019).
URL: *https://store.steampowered.com/app/977950/A$_D$ance$_o$f$_F$ire$_a$nd$_I$ce/*

Agres, K., Forth, J. and Wiggins, G. A. (2017), 'Evaluation of Musical Creativity and Musical Metacreation Systems', *Computers in Entertainment* **14**(3), 1–33.
URL: *http://dl.acm.org/citation.cfm?doid=3023312.2967506*

Ahmed, A. and Ahmad, N. (2017), 'Comparative Analysis of Rote Learning on High and Low Achievers in Graduate and Undergraduate Programs', *Journal of Education and Educational Development* **4**(1), 111.
URL: *http://journals.iobmresearch.com/index.php/JoEED/article/view/982*

Al-Azawi, R., Al-Faliti, F. and Al-Blushi, M. (2016), 'Educational Gamification Vs. Game Based Learning: Comparative Study', *International Journal of Innovation, Management and Technology* pp. 131–136.
URL: *http://www.ijimt.org/index.php?m=contentc=indexa=showcatid=75id=992*

Alexandru Ioan Cuza University of Iasi, Simion, A., Iftene, A., Alexandru Ioan Cuza University of Iasi, Gîfu, D. and Alexandru Ioan Cuza University of Iasi (2021), An Augmented Reality Piano Learning Tool, *in* 'RoCHI - International Conference on Human-Computer Interaction', MATRIX ROM, pp. 134–141.
URL: *http://rochi.utcluj.ro/articole/9/RoCHI2021-Simion.pdf*

Alfred's Basic Adult Piano Course: Lesson Book 1: Piano Book (n.d.).
URL: *https://www.alfred.com/alfreds-basic-adult-piano-course-lesson-book-1/p/00-2236/*

Angeli, D. D. (n.d.), 'The Gameful Museum: Authenticity and Entertainment in the Digital Age', p. 252.

Armstrong, R. L. (1987), 'The Midpoint on a Five-Point Likert-Type Scale', *Perceptual and Motor Skills* **64**(2), 359–362.
URL: *http://journals.sagepub.com/doi/10.2466/pms.1987.64.2.359*

Arts, J. W., Frambach, R. T. and Bijmolt, T. H. (2011), 'Generalizations on consumer innovation adoption: A meta-analysis on drivers of intention and behavior', *International Journal of Research in Marketing* **28**(2), 134–144.
URL: *https://linkinghub.elsevier.com/retrieve/pii/S016781161100022X*

Assessing Creativity 2019 (n.d.), p. 50.

Attwell, P. (1990), 'What is Skill?', *Work and Occupations* **17**(4), 422–448. Publisher: SAGE Publications Inc.
URL: *https://doi.org/10.1177/073088849001700400 3*

Audio Helm for Unity (2014).
URL: *https://tytel.org/audiohelm/*

Audioshield (2016).
URL: *https://store.steampowered.com/app/412740/Audioshield/*

Ausubel, D. P. and Youssef, M. (2010), 'The Effect of Spaced Repetition on Meaningful Retention', *The Journal of General Psychology* . Publisher: Taylor & Francis Group.
URL: *https://www.tandfonline.com/doi/abs/10.1080/00221309.1965.9711263*

Barbosa, J., Malloch, J., Wanderley, M. M. and Huot, S. (n.d.), 'What does " Evaluation " mean for the NIME community?', p. 7.

Barbot, B. and Lubart, T. (2012), 'Creative thinking in music: Its nature and assessment through musical exploratory behaviors.', *Psychology of Aesthetics, Creativity, and the Arts* **6**(3), 231–242.
URL: *http://doi.apa.org/getdoi.cfm?doi=10.1037/a0027307*

Bartle, R. (n.d.), 'HEARTS, CLUBS, DIAMONDS, SPADES: PLAYERS WHO SUIT MUDS', p. 28.

Beat Saber (2019).
URL: *https://store.steampowered.com/app/620980/Beat_saber/*

Better Games Through Usability Evaluation and Testing (2005).
URL: *https://www.gamedeveloper.com/production/better-games-through-usability-evaluation-and-testing*

Bevilacqua, F. (n.d.), 'Gesture Control of Music Systems', p. 90.

Birch, H. (n.d.), 'Motivational Effects of Gamification of Piano Instruction and Practice', p. 87.

Birch, H. J. S. and Woodruff, E. (2017), 'Technical exercise practice: Can piano students be motivated through gamification?', *Journal of Music, Technology and Education* **10**(1), 31–50.
URL: *http://www.ingentaconnect.com/content/10.1386/jmte.10.1.31*$_1$

Bishop, P. A. and Herron, R. L. (n.d.), 'Use and Misuse of the Likert Item Responses and Other Ordinal Measures', p. 6.

Bit.Trip Beat (2020).
URL: *https://www.nintendo.co.uk/Games/Nintendo-Switch-download-software/BIT-TRIP-BEAT-1885042.html*

BIT.TRIP RUNNER on Steam (n.d.).
URL: *https://store.steampowered.com/app/63710/BITTRIP*$_R$*UNNER/*

Bloom, B. S. (1956), *Taxonomy of Educational Objectives: The Classification of Educational Goals*, Longmans, Green. Google-Books-ID: 15_6wAEACAAJ.

Bloom's Taxonomy (n.d.).
URL: *https://cft.vanderbilt.edu/guides-sub-pages/blooms-taxonomy/*

Bobbe, T., Oppici, L., Lüneburg, L.-M., Münzberg, O., Li, S.-C., Narciss, S., Simon, K.-H., Krzywinski, J. and Muschter, E. (2021), 'What Early User Involvement Could Look Like—Developing Technology Applications for Piano Teaching and Learning', *Multimodal Technologies and Interaction* **5**(7), 38. Number: 7 Publisher: Multidisciplinary Digital Publishing Institute.
URL: *https://www.mdpi.com/2414-4088/5/7/38*

Boden, M. A. (2007), 'Creativity in a nutshell', *Think* **5**(15), 83–96.
URL: *https://www.cambridge.org/core/product/identifier/S147717560000230X/type/journal*$_a$*rticle*

Brandt, A., Gebrian, M. and Slevc, L. R. (2012), 'Music and Early Language Acquisition', *Frontiers in Psychology* **3**.
URL: *http://journal.frontiersin.org/article/10.3389/fpsyg.2012.00327/abstract*

Brett, J., Gatzidis, C., Davis, T. and Amelidis, P. (2022), The Crypt of Notation: Rote Learning through Video Games For Adult Beginner Keyboard Learners, *in* 'FDG '22: Proceedings of the 17th International Conference on the Foundations of Digital Games', ACM, Athens Greece, pp. 1–8.
URL: *https://dl.acm.org/doi/10.1145/3555858.3563276*

Brett, J., Gatzidis, C., Davis, T., Amelidis, P., Xu, N. and Gladwell, T. (2021), Learning Through Play; a Study Investigating How Effective Video Games Can Be Regarding Keyboard Education at a Beginner Level, *in* 'The 16th International Conference on the Foundations of Digital Games (FDG) 2021', ACM, Montreal QC Canada, pp. 1–12.
URL: *https://dl.acm.org/doi/10.1145/3472538.3472555*

Brett, J., Gladwell, T., Xu, N., Amelidis, P., Davis, T. and Gatzidis, C. (2020), Developing Games For The Purposes of Rote Learning for Keyboard and Piano, *in* '2020 IEEE Conference on Games (CoG)', IEEE, Osaka, Japan, pp. 724–727.
URL: *https://ieeexplore.ieee.org/document/9231779/*

Burgoyne, J. A., Bountouridis, D., Balen, J. V. and Honing, H. (n.d.), 'HOOKED: A GAME FOR DISCOVERING WHAT MAKES MUSIC CATCHY', p. 6.

Cadence of Hyrule (2020).
URL: *https://www.nintendo.co.uk/Games/Nintendo-Switch-download-software/Cadence-of-Hyrule-Crypt-of-the-NecroDancer-Featuring-The-Legend-of-Zelda-1533129.html*

Callahan, M. R. (n.d.), 'Teaching and Learning Undergraduate Music Theory at the Keyboard: Challenges, Solutions, and Impacts', p. 23.

CASIO (2020).
URL: *https://music.casio.co.uk/blog/lighted-keys-casio-keyboard*

Castillo-Montoya, M. (n.d.), 'Preparing for Interview Research: The Interview Protocol Refinement Framework', p. 22.

Chan, A. S., Ho, Y.-C. and Cheung, M.-C. (1998), 'Music training improves verbal memory', *Nature* **396**(6707), 128–128.
URL: *https://www.nature.com/articles/24075*

Chao-Fernandez, R., Román-García, S. and Chao-Fernandez, A. (2017), 'Analysis of the use of ICT through Music Interactive Games as Educational Strategy', *Procedia - Social and Behavioral Sciences* **237**, 576–580.
URL: *https://www.sciencedirect.com/science/article/pii/S187704281730109X*

Chen, J. (2007), 'Flow in games (and everything else)', *Communications of the ACM* **50**(4), 31–34.
URL: *https://dl.acm.org/doi/10.1145/1232743.1232769*

Chi-hung, C. and Hartwig, K. (2011), 'Teachers' perceptions of declining participation in school music', *Research Studies in Music Education* **33**(2), 123–142.
URL: *http://journals.sagepub.com/doi/10.1177/1321103X11423598*

Chou, A. Y.-k. (2021), 'The 8 Core Drives of Gamification (#8): Loss & Avoidance'.
URL: *https://yukaichou.com/gamification-study/8-loss-and-avoidance/*

Chou, Y.-k. (2019), *Actionable Gamification: Beyond Points, Badges, and Leaderboards*, Packt Publishing Ltd. Google-Books-ID: 9ZfBDwAAQBAJ.

Chow, J., Feng, H., Amor, R. and Wunsche, B. C. (2013), 'Music Education using Augmented Reality with a Head Mounted Display', *User Interfaces* **139**, 8.

Clark, B. (2021), 'The 10 Most Popular Types of Musical Instruments'.
URL: *https://www.musicianwave.com/most-popular-musical-instruments/*

Clark, R. (n.d.), 'Understanding Hand Interactions and Mid-Air Haptic Responses within Virtual Reality and Beyond', p. 173.

Clefs (2020).
URL: *https://play.google.com/store/apps/details?id=com.crazyootka.clefshl=en$_G$Bgl = GB*

Colby, Richard, R. S. (2019), 'Game design documentation: four perspectives from independent game studios', *Communication Design Quarterly* **7**(3), 5–15.
URL: *https://dl.acm.org/doi/10.1145/3321388.3321389*

Colin (2016), 'Staff Wars - A Good Formula for Note Learning - A fun way to learn notes names'.
URL: *https://colinyoung.scot/staff-wars/*

Core Loop in Game Development (2019).
URL: *https://blog.theknightsofunity.com/core-loop-in-game-development/*

Corrigall, K. A. and Trainor, L. J. (2011), 'Associations Between Length of Music Training and Reading Skills in Children', *Music Perception* **29**(2), 147–155.
URL: *https://online.ucpress.edu/mp/article/29/2/147/62530/Associations-Between-Length-of-Music-Training-and*

Cosenza, G. (2006), 'Play Me a Picture, Paint Me a Song: Integrating Music Learning with Visual Art', *General Music Today* **19**(2), 7–11.
URL: *http://journals.sagepub.com/doi/10.1177/10483713060190020103*

Costa-Giorni, E. (2022), '"I Do Not Want to Study Piano!" Early Predictors of Student Dropout Behavior', (1).

Costiuc, S. (2019), 'What Is A Meta-Game?'. Section: design.
URL: *https://www.gamedeveloper.com/design/what-is-a-meta-game-*

Craig, A. B. (2013), Mobile Augmented Reality, *in* 'Understanding Augmented Reality', Elsevier, pp. 209–220.
URL: *https://linkinghub.elsevier.com/retrieve/pii/B9780240824086000072*

Creativity Research in Music Education (n.d.).
URL: *https://journals.sagepub.com/doi/epdf/10.1177/8755123308322280*

Cremaschi, A., Leger, E., Smith, N. and Ilinykh, K. (2015), 'Students who quit music lessons: recent research and recommendations for teachers', *MTNA e-Journal* **6**, 15.

Cremaschi, A. M., Ilinykh, K., Leger, E. and Smith, N. (2015), 'Students Who Quit Music Lessons', p. 13.

Crook, A. (2012), 'Designing Core Loops'.
URL: *https://adriancrook.com/designing-core-loops/*

Crossy Road (2014).
URL: *https://www.crossyroad.com*

Crypt of the Necrodancer (2015).
URL: *https://braceyourselfgames.com/crypt-of-the-necrodancer/*

Cui, K. (2022), 'Artificial intelligence and creativity: piano teaching with augmented reality applications', *Interactive Learning Environments* pp. 1–12.
URL: *https://www.tandfonline.com/doi/full/10.1080/10494820.2022.2059520*

Das, S., Glickman, S., Hsiao, F. Y. and Lee, B. (2017), 'Music Everywhere – Augmented Reality Piano Improvisation Learning System', p. 2.

Deci, E. L. and Ryan, R. M. (2000), 'The "What" and "Why" of Goal Pursuits: Human Needs and the Self-Determination of Behavior', *Psychological Inquiry* **11**(4), 227–268.
URL: *http://www.tandfonline.com/doi/abs/10.1207/S15327965PLI1104*$_0$1

Demirtaş, S. and Süral, S. (2017), 'Development of Pamukkale Piano Learning Style Scale', *International Journal of Assessment Tools in Education* pp. 90–104.
URL: *http://dergipark.gov.tr/doi/10.21449/ijate.339492*

Demski, B. J. and 10/01/10 (n.d.), 'How Music Teachers Got Their Groove Back: Music Instruction Goes Digital -'.
URL: *https://thejournal.com/articles/2010/10/01/how-music-teachers-got-their-groove-back-music-instruction-goes-digital.aspx*

Denham, A. R. (2016), 'Improving the Design of a Learning Game Through Intrinsic Integration and Playtesting', *Technology, Knowledge and Learning* **21**(2), 175–194.
URL: *http://link.springer.com/10.1007/s10758-016-9280-1*

Denisova, A., Guckelsberger, C. and Zendle, D. (2017), Challenge in Digital Games: Towards Developing a Measurement Tool, *in* 'Proceedings of the 2017 CHI Conference Extended Abstracts on Human Factors in Computing Systems', ACM, Denver Colorado USA, pp. 2511–2519.
URL: *https://dl.acm.org/doi/10.1145/3027063.3053209*

Dillon, B. (2009), 'Observations Regarding Recreational Music Making', p. 4.

Donnison, S. and Penn-Edwards, S. (2012), 'Focusing on first year assessment: Surface or deep approaches to learning?', *The International Journal of the First Year in Higher Education* **3**(2), 9–20.
URL: *https://fyhejournal.com/article/view/127*

EarForge – Learn Ear Training (n.d.).
URL: *https://earforge.blog/*

Earpeggio (2018).
URL: *https://musicate.app/earpeggio*

Ebbinghaus, H. (1913), Our knowledge concerning memory., *in* 'Memory: A contribution to experimental psychology.', Teachers College Press, New York, pp. 1–6.
URL: *http://content.apa.org/books/10011-001*

Eli, A. C. (2016), 'Platforma de educație muzicală „Yousician" / "Yousician" - Music Education Platform', p. 5.

Engeser, S., ed. (2012), *Advances in Flow Research*, Springer New York, New York, NY.
URL: *http://link.springer.com/10.1007/978-1-4614-2359-1*

Epistory - Typing Chronicles (2016).
URL: *http://www.epistorygame.com/*

Esposito, N. (2005), 'A Short and Simple Definition of What a Videogame Is'.

Evans, A. D. (n.d.), 'Simulating Airline Operational Responses to Environmental Constraints', p. 185.

Evans, P. (2009), 'Psychological needs and social -cognitive influences on participation in music activities - ProQuest'.
URL: *https://www.proquest.com/openview/07fe0a14996309e9f8abfbd1d3a5aae6/1?pq-origsite=gscholarcbl=18750*

Everwijn, S. E. M., Bomers, G. B. J. and Knubben, J. A. (1993), 'Ability- or competence-based education: Bridging the gap between knowledge acquisition and ability to apply', *Higher Education* **25**(4), 425–438.
URL: *http://link.springer.com/10.1007/BF01383845*

EZ-220 - Overview - Yamaha - UK and Ireland (n.d.).
URL: *https://uk.yamaha.com/en/products/musical*$_i$*nstruments/keyboards/portable*$_k$*eyboards/ez−220/index.html*

Fendt, M. W. and Ames, E. (2019), Using Learning Games to Teach Texas Civil War History to Public Middle School Students, *in* '2019 IEEE Conference on Games (CoG)', IEEE, London, United Kingdom, pp. 1–4.
URL: *https://ieeexplore.ieee.org/document/8847968/*

Feng, X. (2008), 'Measuring Enjoyment of Computer Game Play', p. 11.

Ferianda, M. R., Herdiani, A. and Sardi, I. L. (2018), Increasing Students Interaction in Distance Education Using Gamification, *in* '2018 6th International Conference on Information and Communication Technology (ICoICT)', IEEE, Bandung, pp. 125–129.
URL: *https://ieeexplore.ieee.org/document/8528765/*

Figment (2017).
URL: *https://store.steampowered.com/app/493540/Figment/*

Fitrianti, N. (2022), 'AR Melody : An Augmented Reality Application for Piano Learning'.
URL: *https://medium.com/design-jam-indonesia/ar-melody-an-augmented-reality-application-for-piano-learning-8ecfe33a21c3*

Five Educational Learning Theories (n.d.).
URL: *https://www.wgu.edu/blog/five-educational-learning-theories2005.html*

Fleissig, G., Evans, M. C., Wing, A. and Hammer, J. (n.d.), 'Structural Mismatches in Academic Game Development', **1**(1), 12.

Flinders, D. J. and Uhrmacher, P. B. (2012), *Curriculum and Teaching Dialogue: Vol. 13 # 1 & 2*, IAP. Google-Books-ID: QQMoDwAAQBAJ.

Freitas, S. A. A., Lacerda, A. R. T., Calado, P. M. R. O., Lima, T. S. and Dias Canedo, E. (2017), Gamification in education: A methodology to identify student's profile, *in* '2017 IEEE Frontiers in Education Conference (FIE)', IEEE, Indianapolis, IN, pp. 1–8.
URL: *http://ieeexplore.ieee.org/document/8190499/*

Frogger (1981).
URL: *https://froggerclassic.appspot.com/*

Fu, F.-L., Su, R.-C. and Yu, S.-C. (2009), 'EGameFlow: A scale to measure learners' enjoyment of e-learning games', *Computers & Education* **52**(1), 101–112.
URL: *https://linkinghub.elsevier.com/retrieve/pii/S0360131508001024*

Fukuya, Y., Takegawa, Y. and Yanagi, H. (2013), 'A PIANO LEARNING SUPPORT SYSTEM CONSIDERING MOTIVATION', . *INTRODUCTION* p. 7.

Furuya, S., Flanders, M. and Soechting, J. F. (2011), 'Hand kinematics of piano playing', *Journal of Neurophysiology* **106**(6), 2849–2864.
URL: *https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3234081/*

Gamasutra - Personality And Play Styles: A Unified Model (n.d.).
URL: $https://www.gamasutra.com/view/feature/6474/personality_and_play_styles_a.php?print = 1$

Gamasutra - The Anatomy of a Design Document, Part 1: Documentation Guidelines for the Game Concept and Proposal (n.d.).
URL: $https://www.gamasutra.com/view/feature/3384/the_anatomy_of_a_design_document.php$

Game creation from the pencil to the code. (n.d.).
URL: *https://www.mrgamedev.com*

Gamified sight-reading / sight-reading game? (n.d.). Section: Adult Beginners Forum.
URL: *http://forum.pianoworld.com//ubbthreads.php/topics/2937542.html*

Gemini - Ultraleap documentation (2021).
URL: *https://docs.ultraleap.com/*

Geometry Dash on Steam (n.d.).
URL: $https://store.steampowered.com/app/322170/Geometry_Dash/$

Gerelus, K., Comeau, G. and Swirp, M. (2020), 'Predictors of Piano Student Dropouts', *Intersections* **37**(2), 27–42.
URL: *http://id.erudit.org/iderudit/ 1066616ar*

Git (n.d.).
URL: *https://git-scm.com/*

GitHub (n.d.).
URL: *https://github.com*

Gomes, C. M. C., Figueiredo, M. J. G., Bidarra, J. and Gomes, J. D. C. (2016*a*), Project Flappy Crab: An Edugame for Music Learning, *in* J. M. Spector, D. Ifenthaler, D. G. Sampson and P. Isaias, eds, 'Competencies in Teaching, Learning and Educational Leadership in the Digital Age', Springer International Publishing, Cham, pp. 287–301.
URL: $http://link.springer.com/10.1007/978-3-319-30295-9_18$

Gomes, C. M. C., Figueiredo, M. J. G., Bidarra, J. and Gomes, J. D. C. (2016*b*), Project Flappy Crab: An Edugame for Music Learning, *in* J. M. Spector, D. Ifenthaler, D. G. Sampson and P. Isaias, eds, 'Competencies in Teaching, Learning and Educational Leadership in the Digital Age', Springer International Publishing, Cham, pp. 287–301.
URL: *http://link.springer.com/10.1007/978-3-319-30295-9*$_1$8

Gordon, E. (2012), *Learning Sequences in Music: A Contemporary Music Learning Theory*, GIA Publications. Google-Books-ID: wPjRMgEACAAJ.

Graham, K. and Schofield, D. (2018), 'Rock god or game guru: Using *Rocksmith* to learn to play a guitar', *Journal of Music, Technology and Education* **11**(1), 65–82.
URL: *http://www.ingentaconnect.com/content/10.1386/jmte.11.1.65*$_1$

Graziano, A. B., Peterson, M. and Shaw, G. L. (1999), 'Enhanced learning of proportional math through music training and spatial-temporal training', *Neurological Research* **21**(2), 139–152.
URL: *https://www.tandfonline.com/doi/full/10.1080/01616412.1999.11740910*

Green, L. (2017), *: A Way Ahead for Music Education*, Routledge, London.

Greenberg, B. S., Sherry, J., Lachlan, K., Lucas, K. and Holmstrom, A. (2010), 'Orientations to Video Games Among Gender and Age Groups', *Simulation & Gaming* **41**(2), 238–259.
URL: *http://journals.sagepub.com/doi/10.1177/1046878108319930*

Grier, R. A., Bangor, A., Kortum, P. and Peres, S. C. (2013), 'The System Usability Scale: Beyond Standard Usability Testing', *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* **57**(1), 187–191.
URL: *http://journals.sagepub.com/doi/10.1177/1541931213571042*

GRIS on Steam (n.d.).
URL: *https://store.steampowered.com/app/683320/GRIS/*

Gritton, P. (2019), 'ABRSM (Syllabus)'.

Gurevich, M. and Treviño, J. (2007), 'Expression and Its Discontents: Toward an Ecology of Musical Creation', *New York* p. 6.

Gurevich, M., Verplank, B. and Wilson, S. (n.d.), 'Physical Interaction Design for Music', p. 8.

Hackl, D. and Anthes, C. (n.d.), 'HoloKeys - An Augmented Reality Application for Learning the Piano', p. 5.

Hallam, S. (1998), 'The Predictors of Achievement and Dropout in Instrumental Tuition', *Psychology of Music* **26**(2), 116–132.
URL: *http://journals.sagepub.com/doi/10.1177/0305735698262002*

Hanna, W. (2007), 'The New Bloom's Taxonomy: Implications for Music Education', *Arts Education Policy Review* **108**(4), 7–16.
URL: *http://www.tandfonline.com/doi/abs/10.3200/AEPR.108.4.7-16*

He, X. S. and Loewen, S. (2022), 'Stimulating learner engagement in app-based L2 vocabulary self-study: Goals and feedback for effective L2 pedagogy', *System* **105**, 102719.
URL: *https://linkinghub.elsevier.com/retrieve/pii/S0346251X21002736*

Hemingway, T. J. (n.d.), 'Turn It Up to Eleven: A Study of Guitar Hero and RockBand: Why People Play Them and How Marketers Can Use This Information', p. 74.

Henderson, P. (1993), *Object-oriented specification and design with C$++$*, McGraw-Hill, London.

Hicks, K., Gerling, K., Richardson, G., Pike, T., Burman, O. and Dickinson, P. (2019), Understanding the Effects of Gamification and Juiciness on Players, *in* '2019 IEEE Conference on Games (CoG)', IEEE, London, United Kingdom, pp. 1–8.
URL: *https://ieeexplore.ieee.org/document/8848105/*

Holland, S. J. (n.d.), '[Utilizarea resurselor de învăța[re de tip e-learning de pe platforma E-MusicMaestro pentru dezvoltarea aptitudinilor muzicale esențiale / Using E-MusicMaestro e-learning resources to develop key musicianship skills', p. 8.

Holleman, P. (2019), *Reverse design: Half-life*, CRC Press, Taylor and Francis, Boca Raton.

Holmes, G. and Abington-Cooper, M. (2000), 'Pedagogy vs. Andragogy: A False Dichotomy?', *Journal of Technology Studies* **26**(2).

HoloLens (2016).
URL: *https://www.microsoft.com/en-us/hololens/hardware*

Hotline Miami (n.d.).
URL: *https://store.steampowered.com/app/219150/Hotline$_M$iami/*

How to do thematic analysis (2019).
URL: *https://www.scribbr.com/methodology/thematic-analysis/*

Huang, F., Zhou, Y., Yu, Y., Wang, Z. and Du, S. (2011), Piano AR: A Markerless Augmented Reality Based Piano Teaching System, *in* '2011 Third International Conference on Intelligent Human-Machine Systems and Cybernetics', Vol. 2, pp. 47–52.

Huang, K., Starner, T., Do, E., Weiberg, G., Kohlsdorf, D., Ahlrichs, C. and Leibrandt, R. (2010), Mobile music touch: mobile tactile stimulation for passive learning, *in* 'Proceedings of the 28th international conference on Human factors in computing systems - CHI '10', ACM Press, Atlanta, Georgia, USA, p. 791.
URL: *http://portal.acm.org/citation.cfm?doid=1753326.1753443*

Huck, S. W. and McLean, R. A. (1975), 'Using a repeated measures ANOVA to analyze the data from a pretest-posttest design: A potentially confusing task.', *Psychological Bulletin* **82**(4), 511–518.
URL: *http://doi.apa.org/getdoi.cfm?doi=10.1037/h0076767*

Husson University (n.d.).
URL: *https://online.husson.edu/consumer-behavior-psychoanalytic-theory/*

"I Do Not Want to Study Piano!" Early Predictors of Student Dropout Behavior (n.d.), p. 10.

Inchamnan, W. and Wyeth, P. (2013), Motivation during Videogame Play: Analysing Player Experience in terms of Cognitive Action.

Interpreting Cohen's d | R Psychologist (n.d.).
URL: *https://rpsychologist.com/cohend/*

Jackson, S. (2014), Flow Scales, *in* A. C. Michalos, ed., 'Encyclopedia of Quality of Life and Well-Being Research', Springer Netherlands, Dordrecht, pp. 2305–2308.
URL: *https://doi.org/10.1007/978-94-007-0753-5*$_1$065

Jackson, S. (n.d.), 'Long and Short Measures of Flow: Examining Construct Validity of the FSS-2, DFS-2, and New Brief Counterparts', p. 37.

January 16, R. R. B. and 2007 (2007), 'Rethinking Carrots: A New Method For Measuring What Players Find Most'. Section: design.
URL: *https://www.gamedeveloper.com/design/rethinking-carrots-a-new-method-for-measuring-what-players-find-most-rewarding-and-motivating-about-your-game*

Jensen, M. C. (n.d.), 'Measuring Music Reading: A Guide to Assessment Methods', p. 411.

Johnson, D., Gardner, M. J. and Perry, R. (2018), 'Validation of two game experience scales: The Player Experience of Need Satisfaction (PENS) and Game Experience Questionnaire (GEQ)', *International Journal of Human-Computer Studies* **118**, 38–46.
URL: *https://linkinghub.elsevier.com/retrieve/pii/S1071581918302337*

Jordà, S. (2004), 'Digital Instruments and Players: Part II–Diversity, Freedom and Control', p. 5.

Julia, J., Kurnia, D., Isrokatun, I., Wulandari, H. and Aisyah, I. (2019), 'The use of the Synthesia application to simplify Angklung learning', *Journal of Physics: Conference Series* **1318**(1), 012040.
URL: *https://iopscience.iop.org/article/10.1088/1742-6596/1318/1/012040*

Jungle Music (2016).
URL: *https://play.google.com/store/apps/details?id=air.junglemusicfreehl=en*$_G$*Bgl* $= GB$

Jutras, P. J. (2006), 'The Benefits of Adult Piano Study as Self-Reported by Selected Adult Piano Students', p. 14.

Kaleli, Y. S. (2020), 'The Effect of Computer-Assisted Instruction on Piano Education: An Experimental Study with Pre-service Music Teachers', *International Journal of Technology in Education and Science* **4**(3), 235–246.
URL: *https://ijtes.net/index.php/ijtes/article/view/115*

Kameenui, E. J. and Carnine, D. W. (1998), *Effective Teaching Strategies That Accommodate Diverse Learners*, Prentice-Hall Inc.

Kexugit (2014), 'C# Best Practices - Dangers of Violating SOLID Principles in C#'.
URL: *https://learn.microsoft.com/en-us/archive/msdn-magazine/2014/may/csharp-best-practices-dangers-of-violating-solid-principles-in-csharp*

Kiger, M. E. and Varpio, L. (2020), 'Thematic analysis of qualitative data: AMEE Guide No. 131', *Medical Teacher* **42**(8), 846–854.
URL: *https://www.tandfonline.com/doi/full/10.1080/0142159X.2020.1755030*

Kitamura, T. and Miura, M. (2006), 'Constructing a support system for self-learning playing the piano at the beginning stage', p. 5.

Kleimola, J. (n.d.), 'Visually Augmented Musical Instruments', p. 15.

Kniestedt, I., Lefter, I., Lukosch, S. and Brazier, F. M. (2022), 'Re-framing engagement for applied games: A conceptual framework', *Entertainment Computing* **41**, 100475.
URL: *https://linkinghub.elsevier.com/retrieve/pii/S1875952121000720*

Kultima, A. and Sandovar, A. (2016), Game design values, *in* 'Proceedings of the 20th International Academic Mindtrek Conference', ACM, Tampere Finland, pp. 350–357.
URL: *https://dl.acm.org/doi/10.1145/2994310.2994362*

Kwon, O.-S. and Lee, O.-J. (2012), 'The Effects of the Orff Approach to Music Education Programs on Young Children's Musical Expressiveness', *Korean Journal of Child Studies* **33**(1), 165–181.
URL: *http://childstudies.org/journal/view.php?doi=10.5723/KJCS.2012.33.1.165*

Lalley, J. P. and Miller, R. H. (n.d.), 'THE LEARNING PYRAMID: DOES IT POINT TEACHERS IN THE RIGHT DIRECTION?', p. 17.

Law, L. N. C. and Zentner, M. (2012), 'Assessing Musical Abilities Objectively: Construction and Validation of the Profile of Music Perception Skills', *PLoS ONE* **7**(12), e52508.
URL: *https://dx.plos.org/10.1371/journal.pone.0052508*

Lawlor, J., Thomas, C., Guhin, A. T., Kenyon, K., Lerner, M. D., UCAS Consortium and Drahota, A. (2021), 'Suspicious and fraudulent online survey participation: Introducing the REAL framework', *Methodological Innovations* **14**(3), 205979912110504.
URL: *http://journals.sagepub.com/doi/10.1177/20597991211050467*

Learn Piano Online - Best Online Piano Lessons (n.d.).
URL: *https://www.playgroundsessions.com/*

Lebler, D. (2012), 'Technology and Students' Musicking: Enhancing the Learning Experience', *Theory Into Practice* **51**(3), 204–211.
URL: *http://www.tandfonline.com/doi/abs/10.1080/00405841.2012.690302*

Lesser, A. J. (n.d.), 'VIDEO GAME TECHNOLOGY AND LEARNING IN THE MUSIC CLASSROOM', p. 216.

Levitin, D. J., McAdams, S. and Adams, R. L. (2002), 'Control parameters for musical instruments: a foundation for new mappings of gesture to sound', *Organised Sound* **7**(2), 171–189.
URL: *https://www.cambridge.org/core/product/identifier/S135577180200208X/type/journal*$_{a}$*rticle*

Li, R., Wang, Y. E., Hsiao, C.-P., Davis, N., Hallam, J. and Do, E. (2016), Tactile Teacher: Enhancing Traditional Piano Lessons with Tactile Instructions, *in* 'Proceedings of the 19th ACM Conference on Computer Supported Cooperative Work and Social Computing Companion - CSCW '16 Companion', ACM Press, San Francisco, California, USA, pp. 329–332.
URL: *http://dl.acm.org/citation.cfm?doid=2818052.2869133*

Lightpad Block Studio Edition (2018).
URL: *https://roli.com/products/blocks/lightpad-block-studio-edition*

Lin, C.-H. and Liu, E. Z.-F. (2009), A Comparison between Drill-Based and Game-Based Typing Software, *in* D. Hutchison, T. Kanade, J. Kittler, J. M. Kleinberg, F. Mattern, J. C. Mitchell, M. Naor, O. Nierstrasz, C. Pandu Rangan, B. Steffen, M. Sudan, D. Terzopoulos, D. Tygar, M. Y. Vardi, G. Weikum, Z. Pan, A. D. Cheok, W. Müller and M. Chang, eds, 'Transactions on Edutainment III', Vol. 5940, Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 48–58. Series Title: Lecture Notes in Computer Science.
URL: *http://link.springer.com/10.1007/978-3-642-11245-4*$_5$

Logothetis, N. K. and Sheinberg, D. L. (1996), 'Visual Object Recognition', *Annual Review of Neuroscience* **19**(1), 577–621. _eprint: https://doi.org/10.1146/annurev.ne.19.030196.003045.
URL: *https://doi.org/10.1146/annurev.ne.19.030196.003045*

Lowder, J. E. (1973), 'Evaluation of a Sight-Reading Test Administered to Freshman Piano Classes', *Journal of Research in Music Education* **21**(1), 68–73.
URL: *http://journals.sagepub.com/doi/10.2307/3343981*

LUMI (2020).
URL: *https://playlumi.com/uk*

LUMI - The World's First All-In-One Platform For Learning Music At Home | LUMI (n.d.).
URL: *https://playlumi.com/*

Magnusson, T. (2009), 'Of Epistemic Tools: musical instruments as cognitive extensions', *Organised Sound* **14**(2), 168–176.
URL: *https://www.cambridge.org/core/product/identifier/S1355771809000272/type/journal*$_a$*rticle*

Maguire, M. and Delahunt, B. (2017), 'Doing a Thematic Analysis: A Practical, Step-by-Step Guide for Learning and Teaching Scholars.', **8**(3), 14.

Malloch, J., Birnbaum, D., Sinyor, E. and Wanderley, M. M. (2006), 'Towards a New Conceptual Framework for Digital Musical Instruments', p. 4.

Malone, J. C. and García-Penagos, A. (2014), 'When a clear strong voice was needed: A retrospective review of Watson's (1924/1930) behaviorism', *Journal of the Experimental Analysis of Behavior* **102**(2), 267–287. _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1002/jeab.98.
URL: *https://onlinelibrary.wiley.com/doi/abs/10.1002/jeab.98*

Manturzewska, M. (1990), 'A Biographical Study of the Life-Span Development of Professional Musicians', *Psychology of Music* **18**(2), 112–139.
URL: *http://journals.sagepub.com/doi/10.1177/0305735690182002*

Mario Party™ Superstars (2020).
URL: *https://marioparty.nintendo.com*

Mawbey, W. E. (1973), 'Wastage from Instrumental Classes in Schools', *Psychology of Music* **1**(1), 33–43.
URL: *http://journals.sagepub.com/doi/10.1177/030573567311007*

McKinney, C. and McKinney, C. (1999), 'OSCTHULHU: APPLYING VIDEO GAME STATE-BASED SYNCHRONIZATION TO NETWORK COMPUTER MUSIC', . *Methodology* p. 6.

Meta Quest 2 (2020).
URL: *https://www.meta.com/gb/quest/products/quest-2/*

Miller, K. (2012), *Playing AlongDigital Games, YouTube, and Virtual Performance*, Oxford University Press.
URL: *https://oxford.universitypressscholarship.com/view/10.1093/acprof:oso/9780199753451.001.0001/acp*
9780199753451

Miller, M., Paige, N., Clair, G. and Eckhardt, C. (2019), An Analysis of Peer Presence Social Group Dynamics to Enhance Player Engagement in Multiplayer Games, *in* '2019 IEEE Conference on Games (CoG)', IEEE, London, United Kingdom, pp. 1–8.
URL: *https://ieeexplore.ieee.org/document/8848078/*

Mirza-Babaei, P., Moosajee, N. and Drenikow, B. (2016), Playtesting for indie studios, *in* 'Proceedings of the 20th International Academic Mindtrek Conference', ACM, Tampere Finland, pp. 366–374.
URL: *https://dl.acm.org/doi/10.1145/2994310.2994364*

Mishra, P., Pandey, C., Singh, U., Gupta, A., Sahu, C. and Keshri, A. (2019), 'Descriptive statistics and normality tests for statistical data', *Annals of Cardiac Anaesthesia* **22**(1), 67.
URL: *http://www.annals.in/text.asp?2019/22/1/67/250184*

Momoda, J. (2013), 'The Importance of Core Game Loops - Part 2 of 2'.
URL: *http://jerrymomoda.com/the-core-loop-the-most-important-part-of-a-video-game-part-2-of-2/*

Moreno-Ger, P., Torrente, J., Hsieh, Y. G. and Lester, W. T. (2012), 'Usability Testing for Serious Games: Making Informed Design Decisions with User Data', *Advances in Human-Computer Interaction* **2012**, 1–13.
URL: *http://www.hindawi.com/journals/ahci/2012/369637/*

MRAMUSICPLACE (2017), 'Music Teaching and Bloom's Revised Taxonomy'.
URL: *https://mramusicplace.net/2017/01/12/music-teaching-and-blooms-revised-taxonomy/*

Musicate (n.d.).
URL: *https://musicate.app/*

Musy, M. (2022), 'PianoPlayer'. original-date: 2017-10-16T17:25:47Z.
URL: *https://github.com/marcomusy/pianoplayer*

Nadyrova, D. S. (2016), Embodied Simulation in the Art of Teaching Piano, pp. 156–162.
URL: *https://www.europeanproceedings.com/article/10.15405/epsbs.2016.07.26*

North, A. C., Hargreaves, D. J. and O'Neill, S. A. (2000), 'The importance of music to adolescents', *The British Journal of Educational Psychology* **70 (Pt 2)**, 255–272.

Nowell, L. S., Norris, J. M., White, D. E. and Moules, N. J. (2017), 'Thematic Analysis: Striving to Meet the Trustworthiness Criteria', *International Journal of Qualitative Methods* **16**(1), 160940691773384.
URL: *http://journals.sagepub.com/doi/10.1177/1609406917733847*

NVivo 12 (n.d.).
URL: *https://www.qsrinternational.com/nvivo-qualitative-data-analysis-software/home*

OBS (n.d.).
URL: *https://obsproject.com/*

Octalysis: Complete Gamification Framework - Yu-kai Chou (n.d.).
URL: *https://yukaichou.com/gamification-examples/octalysis-complete-gamification-framework/*

October 06, S. G. R. B. and 2010 (2010), 'Tutorials: Learning To Play'. Section: design.
URL: *https://www.gamedeveloper.com/design/tutorials-learning-to-play*

Olsen, T., Procci, K. and Bowers, C. (2011), Serious Games Usability Testing: How to Ensure Proper Usability, Playability, and Effectiveness, *in* A. Marcus, ed., 'Design, User Experience, and Usability. Theory, Methods, Tools and Practice', Vol. 6770, Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 625–634. Series Title: Lecture Notes in Computer Science.
URL: *http://link.springer.com/10.1007/978-3-642-21708-1*$_7$0

O'Modhrain, S. (2011), 'A Framework for the Evaluation of Digital Musical Instruments', *Computer Music Journal* **35**(1), 28–42.
URL: *http://www.mitpressjournals.org/doi/10.1162/COMJ*$_{a0}$0038

Palmer, W. A., Manus, M. and Lethco, A. V. (2005), *Alfred's Basic Adult Piano Course - Lesson Book 1: Learn How to Play Piano with This Esteemed Method*, Alfred Music. Google-Books-ID: slumlNsU9SwC.

Paradis, E., O'Brien, B., Nimmon, L., Bandiera, G. and Martimianakis, M. A. T. (2016), 'Design: Selection of Data Collection Methods', *Journal of Graduate Medical Education* **8**(2), 263–264.
URL: *http://www.jgme.org/doi/10.4300/JGME-D-16-00098.1*

Pardue, L. S., McPherson, A. and Overholt, D. (n.d.), 'Improving the Instrumental Learning Experience through Complexity Management', p. 8.

Peres, S. C., Pham, T. and Phillips, R. (2013), 'Validation of the System Usability Scale (SUS): SUS in the Wild', *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* **57**(1), 192–196.
URL: *http://journals.sagepub.com/doi/10.1177/1541931213571043*

Pesek, M., Vucko, Z., Savli, P., Kavcic, A. and Marolt, M. (2020), 'Troubadour: A Gamified e-Learning Platform for Ear Training', *IEEE Access* **8**, 97090–97102.
URL: *https://ieeexplore.ieee.org/document/9093057/*

Piano Sight Reading Test (SASR) | Piano Marvel (2018).
URL: *https://pianomarvel.com/feature/sasr*

PianoVision (2022).
URL: *https://www.oculus.com/experiences/quest/5271074762922599/*

Pimsleur, P. (1967), 'A Memory Schedule', *The Modern Language Journal* **51**(2), 73–75. _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1111/j.1540-4781.1967.tb06700.x.
URL: *https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1540-4781.1967.tb06700.x*

Pitts, S. E., Robinson, K. and Goh, K. (2015), 'Not playing any more: A qualitative investigation of why amateur musicians cease or continue membership of performing ensembles', *International Journal of Community Music* **8**(2), 129–147.
URL: *http://www.ingentaconnect.com/content/10.1386/ijcm.8.2.129*$_1$

PlayStation VR (2018).
URL: *https://www.playstation.com/en-gb/ps-vr/*

Poels, K. (2007), 'The fun of gaming: Measuring the human experience of media enjoyment'.

Pretest-Posttest Design | Real Statistics Using Excel (n.d.).
URL: *https://www.real-statistics.com/analysis-of-covariance-ancova/pretest-posttest-design/*

Price, G. E., Dunn, R. and Sanders, W. (1981), 'Reading Achievment and Learning Style Characteristics', *The Clearing House: A Journal of Educational Strategies, Issues and Ideas* **54**(5), 223–226. Publisher: Routledge _eprint: https://doi.org/10.1080/00098655.1981.9957163.
URL: *https://doi.org/10.1080/00098655.1981.9957163*

Pritzker, S. R. and Runco, M. A. (n.d.), 'Encyclopedia of Creativity', p. 1492.

ProQuest (1996).
URL: *https://www.proquest.com/openview/fde3e381a826f193ebe51a94e7102361/1?pq-origsite=gscholarcbl=18750diss=y*

Przybylski, A. K., Rigby, C. S. and Ryan, R. M. (2010), 'A Motivational Model of Video Game Engagement', *Review of General Psychology* **14**(2), 154–166.
URL: *http://journals.sagepub.com/doi/10.1037/a0019440*

Publication quality tables in \LaTeX (2008).
URL: *http://nvd.nist.gov/nvd.cfm?cvename=CVE-2008-1368*

Pérez-Paredes, P. and Sánchez-Tornel, M. (2009), 'Understanding E-Skills in the FLT Context'. ISBN: 9781599049946 Pages: 1-21 Publisher: IGI Global.
URL: *https://www.igi-global.com/chapter/understanding-skills-flt-context/www.igi-global.com/chapter/understanding-skills-flt-context/20018*

Raymaekers, L., Vermeulen, J., Luyten, K. and Coninx, K. (2014), Game of tones: learning to play songs on a piano using projected instructions and games, *in* 'Proceedings of the extended abstracts of the 32nd annual ACM conference on Human factors in computing systems - CHI EA '14', ACM Press, Toronto, Ontario, Canada, pp. 411–414.
URL: *http://dl.acm.org/citation.cfm?doid=2559206.2574799*

Rethinking Carrots: A New Method For Measuring What Players Find Most Rewarding and Motivating About Your Game (n.d.).
URL: *https://www.gamedeveloper.com/design/rethinking-carrots-a-new-method-for-measuring-what-players-find-most-rewarding-and-motivating-about-your-game*

r - How to remove outliers from a dataset (n.d.).
URL: *https://stackoverflow.com/questions/4787332/how-to-remove-outliers-from-a-dataset*

Rhythm Doctor (2021).
URL: *https://store.steampowered.com/app/774181/Rhythm*$_D$*octor/*

Riazi, A. and Riasati, M. (2007), 'Language Learning Style Preferences: A Students Case Study of Shiraz EFL Institutes', *Asian EFL Journal* **9**, 97–125.

Richard A. Bartle: Players Who Suit MUDs (n.d.).
URL: *https://mud.co.uk/richard/hcds.htm*

Rigby, L., Wünsche, B. C. and Shaw, A. (2020), piARno - An Augmented Reality Piano Tutor, *in* '32nd Australian Conference on Human-Computer Interaction', ACM, Sydney NSW Australia, pp. 481–491.
URL: *https://dl.acm.org/doi/10.1145/3441000.3441039*

Rigby, S. and Ryan, R. (2007), 'The Player Experience of Need Satisfaction (PENS)', p. 22.

Rockschool Keyboard Graded Syllabus (2021).
URL: *https://www.rslawards.com/rockschool/graded-exams/keyboard/*

Rogers, K., Weber, M., Röhlig, A., Weing, M., Gugenheimer, J., Könings, B., Klepsch, M., Schaub, F., Rukzio, E. and Seufert, T. (2014), P.I.A.N.O.: Faster Piano Learning with Interactive Projection, *in* 'Proceedings of the Ninth ACM International Conference on Interactive Tabletops and Surfaces - ITS '14', ACM Press, Dresden, Germany, pp. 149–158.
URL: *http://dl.acm.org/citation.cfm?doid=2669485.2669514*

ROLI (2022).
URL: *https://roli.com/*

Rose, D., Heaton, P. and Jones-Bartoli, A. (2015), 'Changes in the well-being of children starting to play musical instruments', **7**(1), 6.

Rosen, D. S. (n.d.), 'The Impact of Explicit Instructions, Expertise, and Personality on Creative Improvisation amongst Jazz Pianists', p. 90.

Roulston, K. (2010), "There is no end to learning': Lifelong education and the joyful learner', *International Journal of Music Education* **28**(4), 341–352.
URL: *http://journals.sagepub.com/doi/10.1177/0255761410381822*

Roulston, K., Jutras, P. and Kim, S. J. (2015), 'Adult perspectives of learning musical instruments', *International Journal of Music Education* **33**(3), 325–335.
URL: *http://journals.sagepub.com/doi/10.1177/0255761415584291*

Rumsey, F. and McCormick, T. (2009), *Sound and recording*, 6. ed edn, Elsesvier, Focal Press, Amsterdam. OCLC: 837120665.

Running, D. J. (2008), 'Creativity Research in Music Education: A Review (1980–2005)', *Update: Applications of Research in Music Education* **27**(1), 41–48.
URL: *http://journals.sagepub.com/doi/10.1177/8755123308322280*

Ruth, N. and Müllensiefen, D. (2021), 'Survival of musical activities. When do young people stop making music?', *PLOS ONE* **16**(11), e0259105.
URL: *https://dx.plos.org/10.1371/journal.pone.0259105*

Ryan, R. M., Rigby, C. S. and Przybylski, A. (2006), 'The Motivational Pull of Video Games: A Self-Determination Theory Approach', *Motivation and Emotion* **30**(4), 344–360.
URL: *http://link.springer.com/10.1007/s11031-006-9051-8*

Ryan, T. (1999), 'The Anatomy of a Design Document Part 1: Documentation Guidelines for the', p. 6.

Ryan, T. G. and Brown, K. (n.d.), 'Musical Creativity: Measures and Learning', *Musical Creativity* p. 17.

Saad, S. S. (n.d.), 'THE EMPLOYING OF MOBILE PHONES AND TABLETS APPLICATIONS IN PIANO TEACHING (A COMPARATIVE STUDY BETWEEN FLOWKEY AND YOUSICIAN)', p. 7.

Salmela, H. and Pärnistö, J. (2009), 'Combining Local and Global Expertise in Services'.

Schell, J. (2008), *The art of game design: a book of lenses*, Elsevier/Morgan Kaufmann, Amsterdam ; Boston. OCLC: ocn213839335.

Schellenberg, E. G. (2006), 'Long-term positive associations between music lessons and IQ.', *Journal of Educational Psychology* **98**(2), 457–468.
URL: *http://doi.apa.org/getdoi.cfm?doi=10.1037/0022-0663.98.2.457*

Seinfeld, S., Figueroa, H., Ortiz-Gil, J. and Sanchez-Vives, M. V. (2013*a*), 'Effects of music learning and piano practice on cognitive function, mood and quality of life in older adults', *Frontiers in Psychology* **4**.
URL: *http://journal.frontiersin.org/article/10.3389/fpsyg.2013.00810/abstract*

Seinfeld, S., Figueroa, H., Ortiz-Gil, J. and Sanchez-Vives, M. V. (2013*b*), 'Effects of music learning and piano practice on cognitive function, mood and quality of life in older adults', *Frontiers in Psychology* **4**.
URL: *http://journal.frontiersin.org/article/10.3389/fpsyg.2013.00810/abstract*

Settles, B. and Meeder, B. (2016), A Trainable Spaced Repetition Model for Language Learning, *in* 'Proceedings of the 54th Annual Meeting of the Association for Computational Linguistics (Volume 1: Long Papers)', Association for Computational Linguistics, Berlin, Germany, pp. 1848–1858.
URL: *https://aclanthology.org/P16-1174*

Sharma, A., Yadav, A., Srivastava, S. and Gupta, R. (2018), 'Analysis of movement and gesture recognition using Leap Motion Controller', *Procedia Computer Science* **132**, 551–556.
URL: *https://linkinghub.elsevier.com/retrieve/pii/S1877050918307403*

Shortt, M., Tilak, S., Kuznetcova, I., Martens, B. and Akinkuolie, B. (2021), 'Gamification in mobile-assisted language learning: a systematic review of Duolingo literature from public release of 2012 to early 2020', *Computer Assisted Language Learning* pp. 1–38.
URL: *https://www.tandfonline.com/doi/full/10.1080/09588221.2021.1933540*

Si Millican, J. (2008), 'A New Framework for Music Education Knowledge and Skill', *Journal of Music Teacher Education* **18**(1), 67–78.
URL: *http://journals.sagepub.com/doi/10.1177/1057083708323146*

Sicart, M. (2014), *Play matters*, Playful thinking, The MIT Press, Cambridge, Massachusetts.

Sidman, M. (1971), 'Reading and Auditory-Visual Equivalences', *Journal of Speech and Hearing Research* **14**(1), 5–13. Publisher: American Speech-Language-Hearing Association.
URL: *https://pubs.asha.org/doi/abs/10.1044/jshr.1401.05*

Sidman, M. (2009), 'Equivalence Relations and Behavior: An Introductory Tutorial', *The Analysis of Verbal Behavior* **25**(1), 5–17.
URL: *http://link.springer.com/10.1007/BF03393066*

Sight Reading Trainer (2016).
URL: *https://sightreading.training/*

Simones, L., Rodger, M. and Schroeder, F. (2017), 'Seeing How It Sounds: Observation, Imitation, and Improved Learning in Piano Playing', *Cognition and Instruction* **35**(2), 125–140.
URL: *https://www.tandfonline.com/doi/full/10.1080/07370008.2017.1282483*

Skerrett, P. (2019), 'Bots started sabotaging my online research. I fought back'.
URL: *https://www.statnews.com/2019/11/21/bots-started-sabotaging-my-online-research-i-fought-back/*

Sonar Beat (2019).
URL: *https://store.steampowered.com/app/892930/Sonar$_B$eat/*

Space Invaders (n.d.).
URL: *https://www.space-invaders.com/about/*

Spiru, L., Marzan, M., Paul, C., Velciu, M. and Garleanu, A. (2019), THE REVERSED MOSCOW METHOD. A GENERAL FRAMEWORK FOR DEVELOPING AGE-FRIENDLY TECHNOLOGIES, *in* 'Proceedings of the 11th International Conference on e-Health 2019', IADIS Press, pp. 75–81.
URL: *http://www.iadisportal.org/digital-library/the-reversed-moscow-method-a-general-framework-for-developing-age-friendly-technologies*

Sprightly Pedagogue (2018), 'Internal Consistency'.
URL: *https://www.youtube.com/watch?v=vnP4KTJHYRs*

Stack (2016).
URL: *https://play.google.com/store/apps/details?id=com.ketchapp.stackhl=en$_G$Bgl = US*

StGeorge, J. (2010), 'THE SUBJECTIVITY OF MUSICAL LEARNING: UNDERSTANDING PARTICIPATION IN INSTRUMENTAL MUSIC INSTRUCTION'.
URL: *http://rgdoi.net/10.13140/RG.2.2.14076.44163*

StGeorge, J., Holbrook, A. and Cantwell, R. (2014), 'Affinity for music: A study of the role of emotion in musical instrument learning', *International Journal of Music Education* **32**(3), 264–277.
URL: *http://journals.sagepub.com/doi/10.1177/0255761413491178*

Sullivan, G. M. and Feinn, R. (2012), 'Using Effect Size—or Why the *P* Value Is Not Enough', *Journal of Graduate Medical Education* **4**(3), 279–282.
URL: *https://meridian.allenpress.com/jgme/article/4/3/279/200435/Using-Effect-Sizeor-Why-the-P-Value-Is-Not-Enough*

Suteparuk, P. (n.d.), 'Detection of Piano Keys Pressed in Video', p. 5.

Sweet, L. (2019), 'Using a learning and skill acquisition plan to develop a learner's knowledge, skills, and professional practice attitudes', *Ultrasound in Medicine & Biology* **45**, S31.
URL: *https://linkinghub.elsevier.com/retrieve/pii/S0301562919312207*

System Usability Scale (SUS) (n.d.).
URL: *https://www.usersense.io/usability-testing/system-usability-scale-sus*

Szilas, N. (2022), 'Serious game design in practice: lessons learned from a corpus of games developed in an academic context', p. 6.

Tadpole Treble (2016).
URL: *https://store.steampowered.com/app/354400/Tadpole$_T$reble/*

Takahashi, K. (2022), 'Minis: MIDI Input for New Input System'. original-date: 2019-10-25T04:46:40Z.
URL: *https://github.com/keijiro/Minis*

Takegawa, Y., Terada, T. and Tsukamoto, M. (2010), 'A PIANO LEARNING SUPPORT SYSTEM CONSIDERING RHYTHM', . *SYSTEM DESIGN* (11), 8.

Tattersall, G. (2019), 'Coding to the Beat - Under the Hood of a Rhythm Game in Unity'. Section: audio.
URL: *https://www.gamedeveloper.com/audio/coding-to-the-beat—under-the-hood-of-a-rhythm-game-in-unity*

Taylor, A. G. (2016), *Develop Microsoft HoloLens Apps Now*, Apress, Berkeley, CA.
URL: *http://link.springer.com/10.1007/978-1-4842-2202-7*

Taylor, D. C. M. and Hamdy, H. (2013), 'Adult learning theories: Implications for learning and teaching in medical education: AMEE Guide No. 83', *Medical Teacher* **35**(11), e1561–e1572. Publisher: Taylor & Francis _eprint: https://doi.org/10.3109/0142159X.2013.828153.
URL: *https://doi.org/10.3109/0142159X.2013.828153*

Team, M. U. (2020), 'What is the Kodály Method?'.
URL: *https://www.musical-u.com/learn/what-is-kodaly-and-how-does-it-relate-to-ear-training/*

Technologies, U. (2005), 'Unity Real-Time Development'.
URL: *https://unity.com/*

Technologies, U. (n.d.), 'Unity Real-Time Development Platform | 3D, 2D VR & AR Engine'.
URL: *https://unity.com/*

Tekinbas, K. S. and Zimmerman, E. (2003), *Rules of Play: Game Design Fundamentals*, MIT Press.

The 13 Basic Principles of Gameplay Design (2009).
URL: *https://www.gamedeveloper.com/design/the-13-basic-principles-of-gameplay-design*

Thematic Analysis (2022).
URL: *https://uk.sagepub.com/en-gb/eur/thematic-analysis/book248481*

The Music of Teaching: Learning to Trust Students' Natural Development (n.d.).
URL: *https://rowman.com/ISBN/9781495059988/The-Music-of-Teaching-Learning-to-Trust-Students'-Natural-Development*

The Official Site for PAC-MAN - Video Games & More (n.d.).
URL: *https://www.pacman.com/en/*

The ONE (2019).
URL: *https://theonemusic.com/*

Theorell, T., Lennartsson, A., Madison, G., Mosing, M. and Ullén, F. (2015), 'Predictors of continued playing or singing – from childhood and adolescence to adult years', *Acta Paediatrica* **104**(3), 274–284.
URL: *https://onlinelibrary.wiley.com/doi/10.1111/apa.12870*

The Other 80% Music Home | MUSIC CREATIVITY THROUGH TECHNOLOGY (n.d.).
URL: *https://musiccreativity.org/*

Theta Music Trainer (n.d.).
URL: *https://trainer.thetamusic.com/en/content/music-training-games*

The Textorcist: The Story of Ray Bibbia (2019).
URL: *https://store.steampowered.com/app/940680/The$_T$ext orcist$_T$he$_S$tory$_o$f$_R$ay$_B$ibbia/*

The Touryst (2019).
URL: *http://thetouryst.shinen.com/*

The Typing of The Dead: Overkill (2013).
URL: *https://store.steampowered.com/app/246580/The$_T$yping$_o$f$_T$he$_D$ead$_O$verkill/*

ToneGym: Ear Training (2018).
URL: *https://www.tonegym.co*

TouchBar, D. S. M. (n.d.), 'EBSCOhost Email Result', p. 4.

Trujano, F., Khan, M. and Maes, P. (2018), ARPiano Efficient Music Learning Using Augmented Reality, *in* T.-T. Wu, Y.-M. Huang, R. Shadiev, L. Lin and A. I. Starčič, eds, 'Innovative Technologies and Learning', Springer International Publishing, Cham, pp. 3–17.

TUNIC on Steam (n.d.).
URL: *https://store.steampowered.com/app/553420/TUNIC/*

Tuparova, D., Tuparov, G., Veleva, V. and Nikolova, E. (2018), Educational computer games and gamification in informatics and information technology education — Teachers' points of view, *in* '2018 41st International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO)', IEEE, Opatija, pp. 0766–0771.
URL: *https://ieeexplore.ieee.org/document/8400142/*

van Dijk, E. M., Lingnau, A. and Kockelkorn, H. (2012), Measuring enjoyment of an interactive museum experience, *in* 'Proceedings of the 14th ACM international conference on Multimodal interaction - ICMI '12', ACM Press, Santa Monica, California, USA, p. 249.
URL: *http://dl.acm.org/citation.cfm?doid=2388676.2388728*

Vaughn, K. (2000), 'Music and Mathematics: Modest Support for the Oft-Claimed Relationship', *Journal of Aesthetic Education* **34**(3/4), 149.
URL: *https://www.jstor.org/stable/3333641?origin=crossref*

Virtala, P., Huotilainen, M., Putkinen, V., Makkonen, T. and Tervaniemi, M. (2012), 'Musical training facilitates the neural discrimination of major versus minor chords in 13-year-old children: Musical training facilitates neural discrimination of chords', *Psychophysiology* pp. n/a–n/a.
URL: *https://onlinelibrary.wiley.com/doi/10.1111/j.1469-8986.2012.01386.x*

Visi, F., Schramm, R. and Miranda, E. (2014), Gesture in performance with traditional musical instruments and electronics: Use of embodied music cognition and multimodal motion capture to design gestural mapping strategies, *in* 'Proceedings of the 2014 International Workshop on Movement and Computing - MOCO '14', ACM Press, Paris, France,

pp. 100–105.
URL: *http://dl.acm.org/citation.cfm?doid=2617995.2618013*

VIVE (2016).
URL: *https://www.vive.com/uk/*

VIVE Tracker (3.0) (2020).
URL: *https://www.vive.com/uk/accessory/tracker3/*

Wanderley, M. M. (n.d.), 'Gestural Control of Music', p. 14.

Wanderley, M. M. and Orio, N. (2002), 'Evaluation of Input Devices for Musical Expression: Borrowing Tools from HCI', *Computer Music Journal* **26**(3), 62–76.
URL: *http://www.mitpressjournals.org/doi/10.1162/014892602320582981*

Wandersong (2018).
URL: *https://store.steampowered.com/app/530320/Wandersong/*

Wang, L. (2022*a*), 'The Skill Training of Reading Music in the Teaching of Solfeggio and Ear Training in the New Media Environment', *Applied Bionics and Biomechanics* **2022**, 1–11.
URL: *https://www.hindawi.com/journals/abb/2022/8209861/*

Wang, Y. (2022*b*), 'Music education: Which is more effective – Traditional learning or the introduction of modern technologies to increase student motivation?', *Learning and Motivation* **77**, 101783.
URL: *https://linkinghub.elsevier.com/retrieve/pii/S0023969022000030*

WarioWare: Get It Together! (2020).
URL: *https://www.nintendo.co.uk/Games/Nintendo-Switch-games/WarioWare-Get-It-Together–1987424.html*

Weber, B. (2011), 'Gerald A. Lawson, a Pioneer in Video Games, Dies at 70', *The New York Times* .
URL: *https://www.nytimes.com/2011/04/14/technology/personaltech/14lawson.html*

Wee, C. C. and Mariappan, M. (2017), Finger tracking for piano playing through contactless sensor system: Signal processing and data training using artificial neural network, *in* '2017 IEEE 2nd International Conference on Automatic Control and Intelligent Systems (I2CACIS)', IEEE, Kota Kinabalu, pp. 41–45.
URL: *http://ieeexplore.ieee.org/document/8239030/*

West, C. (2015), 'Developing Internal Musicianship in Beginning Band by Teaching the "Big 5"', *Music Educators Journal* **101**(3), 101–106.
URL: *http://journals.sagepub.com/doi/10.1177/0027432114565392*

What is a DNA connector (2018).
URL: *https://support.roli.com/support/solutions/articles/36000027922-what-is-a-dna-connector-*

What is Skill? (n.d.).
URL: *https://journals.sagepub.com/doi/epdf/10.1177/0730888490017004003*

Wolf, A. and Kopiez, R. (2018), 'Development and Validation of the Musical Ear Training Assessment (META)', *Journal of Research in Music Education* **66**(1), 53–70.
URL: *http://journals.sagepub.com/doi/10.1177/0022429418754845*

Wong, A. C. N., Wong, Y. K., Lui, K. F. H., Ng, T. Y. K. and Ngan, V. S. H. (2019), 'Sensitivity to configural information and expertise in visual word recognition.', *Journal of Experimental Psychology: Human Perception and Performance* **45**(1), 82–99.
URL: *http://doi.apa.org/getdoi.cfm?doi=10.1037/xhp0000590*

Wong, Y. K., Lui, K. F. H. and Wong, A. C.-N. (2021), 'A reliable and valid tool for measuring visual recognition ability with musical notation', *Behavior Research Methods* **53**(2), 836–845.
URL: *https://link.springer.com/10.3758/s13428-020-01461-w*

Xiao, X. and Ishii, H. (2011), MirrorFugue: communicating hand gesture in remote piano collaboration, *in* 'Proceedings of the fifth international conference on Tangible, embedded, and embodied interaction - TEI '11', ACM Press, Funchal, Portugal, p. 13.
URL: *http://portal.acm.org/citation.cfm?doid=1935701.1935705*

Xu, Y., Pace, S., Kim, J., Iachini, A., King, L. B., Harrison, T., DeHart, D., Levkoff, S. E., Browne, T. A., Lewis, A. A., Kunz, G. M., Reitmeier, M., Utter, R. K. and Simone, M. (2022), 'Threats to Online Surveys: Recognizing, Detecting, and Preventing Survey Bots', *Social Work Research* **46**(4), 343–350.
URL: *https://doi.org/10.1093/swr/svac023*

Yang, H. (2021), 'Research on the Application of Computer Audio Technology in Piano Education', *Journal of Physics: Conference Series* **1915**(3), 032074.
URL: *https://iopscience.iop.org/article/10.1088/1742-6596/1915/3/032074*

Yang, Q. and Essl, G. (n.d.), 'Visual Associations in Augmented Keyboard Performance', p. 4.

You, Y. (n.d.), 'Music Note Learning Card Game Design', p. 24.

Zammitto, V. (2018), Games User Research as part of the development process in the game industry: Challenges and best practices, *in* A. Drachen, P. Mirza-Babaei and L. Nacke, eds, 'Games User Research', Oxford University Press, p. 0.
URL: *https://doi.org/10.1093/oso/9780198794844.003.0002*

Zentner, M. and Strauss, H. (2017), 'Assessing musical ability quickly and objectively: development and validation of the Short-PROMS and the Mini-PROMS: Assessing musical ability', *Annals of the New York Academy of Sciences* **1400**(1), 33–45.
URL: *https://onlinelibrary.wiley.com/doi/10.1111/nyas.13410*

Zinn, T. E., Newland, M. C. and Ritchie, K. E. (2015), 'The efficiency and efficacy of equivalence-based learning: A randomized controlled trial', *Journal of Applied Behavior Analysis* **48**(4), 865–882. _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1002/jaba.258.
URL: *https://onlinelibrary.wiley.com/doi/abs/10.1002/jaba.258*

ZType (2011).
URL: *https://zty.pe/*

Zuk, J., Andrade, P. E., Andrade, O. V. C. A., Gardiner, M. and Gaab, N. (2013), 'Musical, language, and reading abilities in early Portuguese readers', *Frontiers in Psychology* **4**.
URL: *http://journal.frontiersin.org/article/10.3389/fpsyg.2013.00288/abstract*

Zumel, N. (2019), 'Cohen's D for Experimental Planning'.
URL: *https://win-vector.com/2019/06/18/cohens-d-for-experimental-planning/*

Zuo, T., Birk, M. V., van der Spek, E. D. and Hu, J. (2022), 'The mediating effect of fantasy on engagement in an AR game for learning', *Entertainment Computing* **42**, 100480.
URL: *https://linkinghub.elsevier.com/retrieve/pii/S1875952122000040*

NoteWorks (2012).
URL: *https://apps.apple.com/gb/app/noteworks/id546003758*

Appendix A

Study Questions

A.1 Study One Questions

Timeframes
A rough estimation of how long each interview will take is outlined below; these times will vary per individual but hopefully provides a reasonably accurate guide.

- Introduction and consent: 10 minutes
- Introduction Questions: 20 minutes
- Main Play Sessions with Questions: 5 minutes with 4 games, 20 minutes
- Closing Questions and Remarks: 10 minutes
- Total Time: 1 Hour

Introductions & Instructions
An introduction to the lead researcher and the background/reason for conducting this study and research. Following this, a brief outline of what will take place during the interview will be offered and any questions or concerns can be answered at this stage.

Recording, Ethical and Data Consent
A breakdown of how the collected data will be used, how this information will remain anonymous and any ethical issues that arise from this will be discussed and approved by the participant; a sheet will be provided with this information and any NDA/relevant consent forms will be signed.

Introduction Questions
Questions that are indented are considered follow up or probing questions.

1. How old are you?
2. Music Experience/Preferences:
    a. Do you take any lessons or have taken any lessons in the past?
        i. Anything in particular that you found repetitive or mundane?
    b. Do you own any instruments?
        i. How much experience do you have with the instrument?
        ii. What do you find the most tedious (boring) about learning [piano/keyboard]?
        iii. [If a lapser] Any reasons to originally stopping learning?
        iv. [Lapser] What made you want to start again/start initially?
        v. Why do you want to learn to play [keys]/general musicianship?
        vi. What prevents you from starting learning (e.g. embarrassment/nervous etc.)?
        vii. How long would you be willing to spend each day for learning?
        viii. How would you go about learning to play a keyboard/piano?
            a. Prompts: Teacher, online videos, friends etc.
        ix. Have you tried using learning applications e.g. Yousician?
            a. Were they helpful/beneficial for your learning experience?
    c. How creative of a person do you feel you are?
    d. How often do you listen to music?
        i. Any particular genres that stand out?
3. Are you a gamer at all; do you play video games?
    a. How often do you play games per week?

    b. Have you/do you play any musical games or games revolved around sound/music?
    c. What genre are you typically fond of?
        i. Specific Games; Reasoning?
d. Why do you play the games you mentioned?
    e. Do you typically play on a mobile, console etc.? How do you play?

These are the questions that will be asked after each game has been played:

1. A question for those who have used other learning applications is appropriate; how would you compare this to the scale practise in [e.g. Yousician]?
2. How would you describe your experience?
    a. How educational did you find each game (i.e. did you learn or take something away from it?) [Likert scale 1-5]
    b. Did you find the experience fun? [Likert scale 1-5]
    c. Is there anything in particular that stood out, either negative or positive?
    d. Thoughts on the layout of the score etc. on screen and the design of each game?
    e. How would you describe the overall theme of the game?
    f. Would you change the design or style of the game?
    g. How would make it different; any features you would like to see or any existing features you would remove or change?
3. What did you like the most?
    a. And the least?
4. What caused, if any, stress or frustration?
5. I noticed you spent the most time on [particular game] and less time playing [game]; any reasons for this?
6. I noticed you seemed a bit confused at one point; any insights you can share into why this may be?
7. Observational Points:
    a. Navigation of menus and overall experience
    b. Understanding the concept of each game
    c. Understanding of what is being taught or practised
    d. Particular mechanics or features that they struggled with or used a significant amount?
    e. Are there any areas in which getting a high score is particularly easy or hard?
8. How likely is it would you recommend this game to a friend learning keyboard, theory etc.? (1-5)
9. If you could use this as a practice tool alongside typical learning methods, would you?
    a. How often? i.e. would this replace a typical practice tool and could you see yourself using it more if it could teach more lessons and provide more than simple things to practice?
10. Any remaining comments about your experience?

Closing Questions and Remarks

Closing remarks which thank the participant for coming in and will go over the purpose of the study once more and ensure participants of their data anonymity when discussing this data.

1. Of all the games played today, which was your preferred one?
a. And why do you say that?
2. Any last notes regarding the hardware and would you be inclined to come back for testing?
3. Is there any other information regarding your experience that you think would be useful for me to know?
4. Any creativity related questions? (Extension; could feed much later into the project)

Recording devices switched off.

Interviewer Reflection

After the participant has left, the head researcher/interviewer will take five minutes to reflect on the answers given and organise the work space for the next interview. After each interview has been conducted, a reflection sheet will be provided to fill out after each interview to ensure the data and experience is captured in as much detail as possible.

A.2 Study Two Questions

Timeline

A rough estimation of how long each interview will take is outlined below; these times will vary per individual but provides a reasonably accurate guide.

- **Introduction and Questions:** 10-15 minutes
- **Main Play Sessions with Questions:** ~45 minutes (depending on users' willingness to play for longer/give longer answers)
- **Closing Questions and Remarks:** 10 minutes
- **Total Time:** ~60 minutes

Introductions and Instructions

An introduction to the lead researcher and the background/reason for conducting this study and research will be provided. Following this, a brief outline of what will take place during the interview will be offered and any questions or concerns can be answered at this stage.

Recording, Ethics and Data Consent

A breakdown of how the collected data will be used, how this information will remain anonymous and any ethical issues that arise from this will be discussed and approved by the participant; a sheet will be provided with this information and any NDA/relevant consent forms will be signed.

Introduction Questions

Questions that are indented are considered follow-up or probing questions.

1. State what age range they fall into
2. Music Experience/Preferences:
    a. Do you own any instruments?
        i. How much experience do you have with the instrument/music in general?
        ii. Why do you want to learn to play [chosen instrument]/general musicianship?
        iii. How would/did you go about learning to play a keyboard/piano?
            1. Prompts: Teacher, online videos, friends etc.
        iv. Anything in particular that you found tedious and/or mundane about learning or practising your chosen instrument?
        v. [Lapser] Any reasons to originally stopping learning?
            1. [Lapser] What made you want to start again/start initially?
    b. How long would you be willing to spend each day for learning?
        i. What prevents you or puts you off hitting this goal?
        ii. What does this practise typically look like?
            1. Where can games be most effective?
    c. Have you tried using learning applications e.g. Yousician?
        i. Were they helpful/beneficial for your learning/teaching experience?
            1. Useful, risk of incorrect playing, 'hamburger model'
3. Do you play video games?
    a. What type of games do you typically play – preferred genre/platform?

        i. Why do you play the games you mentioned?
            1. Escapism, relaxing, pure enjoyment/personality (who you are) etc.
    b. How often do you play games per week? [List: once a day, 2/3 times a week, once a week, when I get the chance]

Questions & Observations Post Game Play Session

Open-Ended Questions Relating to the Overall Experience

1. How would you describe your experience?
    a. Thoughts on the design of the game?
    b. Would you change the overall design or style of the game?
        i. General comments on the theme; would you change it or add to it?
    c. Any features you would like to see or any major existing features you would remove or change?
2. What caused, if any, stress or frustration? (Observational probes)

Questions Regarding Specific Mechanics

A table of each game and consequent mechanic/design choice can be made available. Users will play each game with and without the varied mechanic/design and then be asked simple preference questions and probing questions into why. The variances are not major (for example, do users prefer to choose settings or use a set up level) and there are only a few variances per game therefore, testing these specific mechanics should take no longer than a few minutes – allowing users to spend the majority of time playing the core of each game rather than discussing minor changes.

Questions Regarding Educational Impact

1. How educational did you find this game (i.e. did you feel like you had improved your skills/felt more confident playing?) [Likert scale 1-5]
    a. Any reasoning for this score?
    b. What can be done to increase this score?
        i. Specific design choices
        ii. Obvious changes to incorrect features (e.g. a note may be in the wrong place or sound may be wrong etc.)
2. How likely would it be for you to use this as a practise tool alongside your learning? [Likert Scale 1-5]
    a. [if low score] What could be implemented to increase this likeliness?
    b. [if high score] How often? i.e. could you see yourself using it more if it could teach more lessons and provide more than simple things to practise? (Serious application)
3. How likely is it would you recommend this game to a friend learning keyboard, theory etc.? [Likert scale 1-5]

Questions Regarding Usability

1. How difficult did you find the game's menu and setup to navigate? [Likert scale 1-5]
    a. Any reasons for this? (Follow up observation questions)
    b.

    c. What can be done to improve the overall UX?
2. How difficult was it to grasp the concept of the game? [Likert 1-5]
    a. Observations should highlight this
    b. If low, any reasons for this? (Follow up observation questions)
3. Was the use of the lights useful or potentially distracting?

Questions Pertaining to Competence (feeling of fun, competition, being good at the game and being able to apply a level of skill)

1. How satisfising did you find the game? [Likert Scale 1-5]
    a. Did you find a specific game mechanic satisfying?
    b. Was there something in particular that helped this feeling?
        i. Aesthetics and Sounds
            1. Specific design choices e.g. flashing screen etc.
2. How challenged did you feel playing this game? [Likert Scale 1-5]
3. How skilful did you feel playing this game? [Likert Scale 1-5]
    a. Why do you feel this way?
    b. Did you feel as though you were applying a specific skill?
    c. Was the difficulty gradient too steep or shallow?
4. How likely would you be to return to the game? [Likert Scale 1-5]
    a. Why is this?
        i. High scores/leader board?
        ii. Getting to next level? Unlock the next level?
5. How immersed did you feel when playing? [Likert Scale 1-5]
    a. Were you engrossed by the gameplay?
    b. The music and sounds?
    c. The story or specific designs?

Questions Pertaining to Autonomy (Choice perception)

1. How much choice did you feel you had during gameplay? [Likert Scale 1-5]
    a. What lead you to give that score?
        i. E.g. the ability to pick up bonus points but risk losing a life
        ii. The idea of playing on beat for extra points
        iii. Or a lack of choice such as, you could only play the correct note
2. Did you feel as though your choices had meaning?
    a. E.g. users could go down path left or right but always end up in the same place
3. Did you feel as though you could/wanted to explore the game? [Likert Scale 1-5]
    a. Why provide this score?
        i. Different settings, themes, shop items etc.
        ii. Actual exploration of themed levels
        iii. Exploring the intricacies of the game itself
    b. Did the user attempt to ‘break’ the game mechanics?
    c. Did the user desire to replay a specific part or level to beat their previous score and see how the mechanics/rules can be bent to maximise score?

Questions Pertaining to Relatedness (social aspect, leader boards, badges etc.)

1. Was recording scores (streak, incorrect, correct) a motivator to play again?
    a. In what capacity, the idea of beating your previous score or would you prefer to compare against other players?
        i. Beating the main leader boards?
    b. Would this game benefit from social elements?
        i. E.g. personal profiles with total time played, total correct scores, badge collections etc. which can be directly compared against?

Closing Remarks

Closing remarks which thank the participant for coming in and will go over the purpose of the study once more and ensure participants of their data anonymity when discussing this data.

1. Of all the games played today, which was your preferred one?
    a. And why do you say that?
2. Would you like to give any final comments regarding the games (and the testing itself)?
3. Would you be inclined to come back for a longer form of testing?

Recording devices switched off.

Interviewer Reflection

After the participant has left, the head researcher/interviewer will take five minutes to reflect on the answers given and organise the work space for the next interview. After each interview has been conducted, a reflection sheet will be provided to fill out after each interview in order to ensure the data and experience is captured in as much detail as possible.

A.3 Study Three Questions

Introduction Questions

Questions that are indented are considered follow-up or probing questions.

1. State what age range they fall into
2. Music Experience/Preferences:
    a. Do you own any instruments?
        i. How much experience do you have with the instrument/music in general?
        [The instrument which has the most experience will be the 'primary' instrument for a given participant]
    b. How long would you be willing to spend each day practising?
        i. What prevents you from hitting this goal?
3. Do you play video games?
    a. What type of games do you typically play – preferred genre/platform?
    b. How often do you play games per week? [once a day, 2/3 times a week, once a week, when I get the chance]

Questions & Observations Post/During Game Play Session

Open-Ended Questions Relating to the Overall Experience

1. How would you describe your experience?
    a. Participants should be free to discuss their experience whilst they are playing but will also provide answers post session
    b. Would you change the overall design or style of the game?
    c. Any features you would like to see or any major existing features you would remove or change?

Questions Regarding Educational Impact

1. How educational did you find this game (i.e. did you feel like you had improved the skill of reading music at the keyboard/felt more confident reading music in general?) [Likert scale 1-5]
    a. Any reasoning for this score?
2. How likely would it be for you to use this as a practise tool alongside your learning? [Likert Scale 1-5]
    a. How often? i.e. could you see yourself using it more if it provide more than simple things to practise e.g., advanced notation, reading times etc.? (Serious application)

Questions Regarding Usability [1,2]

1. How difficult did you find the game's menu and setup to navigate? [Likert scale 1-5]
    a. Any reasons for this? (Follow up observation questions)
    b. What can be done to improve the overall UX?
2. How difficult was it to grasp the concept of the game? [Likert 1-5]
    a. Observations should highlight this
    b. Difficulty curves; was it too easy or too hard?
3. What caused, if any, stress or frustration? (Observational probes)

Questions Pertaining to Competence (feeling of fun, competition, being good at the game and being able to apply a level of skill)

1. How satisfising did you find the game? [Likert Scale 1-5]
    a. What lead you to give that score?
        i. Aesthetics and Sounds
            1. Specific design choices e.g. flashing screen etc.
2. How challenged did you feel playing this game? [Likert Scale 1-5]
    a. What lead you to give that score?
3. How skilful did you feel playing this game? [Likert Scale 1-5]
    a. What lead you to give that score?
4. How likely would you be to return to the game? [Likert Scale 1-5]
    a. What lead you to give that score?
        i. High scores/leader board?
        ii. Getting to next level? Unlock the next level?
5. How immersed did you feel when playing? [Likert Scale 1-5]
    a. Were you engrossed by the gameplay?
    b. The music and sounds?
    c. The story or specific designs?

Questions Pertaining to Autonomy (Choice perception)

1. How much choice did you feel you had during gameplay? [Likert Scale 1-5]
    a. What lead you to give that score?
        i. Mechanical/menu choices
        ii. The ability to pick up bonus points but risk losing a life
        iii. The idea of playing on beat for extra points
        iv. Or a lack of choice such as, you could only play the correct note
2. Did you feel as though you could/wanted to explore the game? [Likert Scale 1-5]
    a. What lead you to give that score?
        i. Different settings, themes, shop items etc.
    b. (Observation) Did the participant attempt to ‘break’ the game mechanics?
    c. (Observation) Did the participant desire to replay a specific part or level to beat their previous score and see how the mechanics/rules can be bent to maximise score (the sense of replay ability)?

Closing Remarks

Closing remarks which thank the participant for coming in and will go over the purpose of the study once more and ensure participants of their data anonymity when discussing this data.

1. Would you like to give any final comments regarding the game (and the testing itself)?
2. Would you be inclined to come back for a longer form of testing?

Recording devices switched off.

A.4 Study Four Questions

Ethical Consent

A breakdown of how the collected data will be used, how this information will remain anonymous and any ethical issues that arise from this will be discussed and approved by the participant; a sheet will be provided with this information (sent via email in PDF format). Participants will be sent the attached agreement form and will sign this electronically before sending it back to the researcher; any participant that does not send back the signed form, will not be able to participate.

Introduction/Background Survey

[1] State what age range you fall into (years old):
- a. 18-24
- b. 25-34
- c. 35-44
- d. 45-54
- e. 55-64
- f. 65+

[2] Please state your sex
- a. Male
- b. Female
- c. Prefer not to say

[3] Please state what desktop PC you own
- a. Apple based
- b. Windows based
- c. Other [please specify]

[4] Music Experience/Preferences:
- a. Do you own any instruments?
  - i. How much experience do you have with the instrument/music in general? [The instrument which has the most experience will be the 'primary' instrument]
  - ii. Please state how you have learned so far (online videos, books, teacher etc.)
  - iii. Have you ever undertaken any formal musical training? If yes, briefly describe
  - iv. How confident do you feel reading sheet music/musical notation [out of 10]? Where 1 is never attempted to read sheet music and 10 is can sight-read without any issues and with maximum confidence
- b. How long do you currently spend/ would you be willing to spend each day practising (minutes)?
  - i. 5
  - ii. 10-20
  - iii. 30-60
  - iv. 60-120
  - v. 120+
  - vi. What prevents you from hitting this goal (if you do not achieve it regularly)?

[5] Do you play video games?

a. What type of games do you typically play – preferred genre/platform?
b. How often do you play games per week?
    i. 3 or more hours per day
    ii. At least 1-2 hours everyday
    iii. Once a day
    iv. 2/3 times a week
    v. Once a week, when I get the chance
    vi. Rarely play

Mid-Week Survey (Optional)

[1] How much did you use your practice tool this week?
    a. Only for the allotted 15 minutes
    b. 15-30 minutes
    c. 30-60 minutes
    d. 60-120 minutes
    e. 120+ minutes
[2] What did you do regarding playing/learning with your instrument? (if you had practised outside the allotted 15 minutes of practice time)
[3] Did you feel more inclined to practice or learn this week (compared to your average week)?
    a. Do you feel the solution helped increase your motivation to play and learn?
[4] Do you felt the practice tool helped you improve your playing form or helped you feel more confident/competent at the keyboard?

End of Study Survey

Open-Ended Questions Relating to the Overall Experience

[1] How would you describe your experience with your practice solution?
    a. Would you change the overall design or style of the game/tool?
    b. Any features you would like to see or any major existing features you would remove or change?

Questions Regarding Educational Impact

[1] How educational did you find this game (i.e. did you feel like you had improved the skill of reading music at the keyboard/felt more confident playing keyboard in general?) [Likert scale 1-5]
    a. Any reasoning for this score?
[2] How likely would it be for you to use this as a practise tool alongside your learning (outside of this experiment)? [Likert Scale 1-5]
    a. How often? i.e. could you see yourself using it more if it provide more than simple things to practise e.g., advanced notation, reading times etc.?

Questions Pertaining to participants learning/playing habits using either solution

[1] How much did you play your instrument throughout the session on a daily basis?
    a. Only for the allotted 15 minutes
    b. 15-30 minutes

c. 30-60 minutes
d. 60-120 minutes
e. 120+ minutes

[2] What did you do regarding playing/learning with your instrument? (if you had practised outside the allotted 15 minutes of practice time)

[3] Did you feel more inclined to practice or learn (compared to your average week)?
   a. Do you feel the solution helped increase your motivation to play and learn?

[4] Do you felt the practice tool helped you improve your playing form or helped you feel more confident/competent at the keyboard?

Questions Regarding Usability & SUS [4,5, 6]

[1] I found it unnecessarily complicated [Likert scale 1-5]
   a. Any reasons for this?
   b. What can be done to improve the overall UX?

[2] I found the product easy to use [Likert scale 1-5]

[3] I found the different features of the solution well integrated with each other [Likert scale 1-5]

[4] I found the concept of the solution difficult to grasp/understand [Likert 1-5]

[5] The solution matched my skill level well [Likert scale 1-5]

[6] I can imagine most people would quickly get on with the solution [Likert scale 1-5]

[7] I felt confident using the solution [Likert scale 1-5]

[8] What caused, if any, stress or frustration?

Questions Pertaining to Competence (feeling of fun, competition, how much participants felt they were in a state of flow and challenge they felt during the session)

[1] How satisfising did you find the solution? [Likert Scale 1-5]
   a. What lead you to give that score?
      i. Aesthetics and Sounds
         1. Specific design choices e.g. flashing screen etc.

[2] I felt just the right amount of challenge [Likert Scale 1-5]
   a. What lead you to give that score?

[3] How skilful did you feel using the solution? [Likert Scale 1-5]
   a. What lead you to give that score?

[4] How likely would you be to return to the solution? [Likert Scale 1-5]
   a. What lead you to give that score?
      i. High scores/leaderboards?
      ii. ii. Getting to next level? Unlock the next level?

[5] How immersed did you feel when practising? [Likert Scale 1-5]
   a. Were you engrossed by the gameplay?
   b. The music and sounds?
   c. The story or specific designs?

[6] I did not notice time passing [Likert Scale 1-5]

Questions Pertaining to Autonomy (Choice perception)

[1] How much choice did you feel you had during each practice session? [Likert Scale 1-5]

a. What lead you to give that score?
    i. Mechanical/menu choices
    ii. The ability to pick up bonus points but risk losing a life
    iii. The idea of playing on beat for extra points
    iv. Or a lack of choice such as, you could only play the correct note

[2] Did you feel as though you could/wanted to explore the solution? [Likert Scale 1-5]

a. What lead you to give that score?
    i. Different settings, themes, shop items etc.
    ii. (Observation) Did the participant desire to replay a specific part or level to beat their previous score and see how the mechanics/rules can be bent to maximise score (the sense of replay ability)?

Appendix B

Analytical Strategies and Game Inspirations

B.1 Qualitative Analytical Strategy (Nvivo12)

This analytical strategy is based on a series of interviews revolving around a series of learning video games with specific purposes relating to keyboard/piano education. Through a series of interviews, we wanted to establish and inductively prove what we have deduced thus far; the reasons for beginner instrumental learners to give up on learning, the fundamental aspects of a music learning journey which is deemed repetitive, tedious and boring. With this deduction, we created several prototype games to help solve this issue of boredom and high drop off rates. Through our analysis of each interview, we aim to provide evidence to our deductions whilst also finding other themes relating to this problem. We also aim to find recurring themes relating specifically to each game and the experience of it, the overall study itself (regarding improving for next time) and to help narrow down the scope of this research in order to help create criteria and build a system which can be used as a catalyst to test our solutions against our given problem. This approach does not commence with a prior hypothesis to be tested and proved but with a focus of inquiry that takes the researcher on a voyage of discovery; specifically relating to the effectiveness of each game, quality of the user experience, the overall testing methodological approach and how to improve this. The aim is to improve each game and ensure that it matches the specific criteria (leading to a solution for our given problem) whilst also ensuring the way we test the validity of these games is thorough enough and is highly relatable to our given problem (i.e., ensure these solutions can actually help solve our problem).

Thematic analysis involves the identification of patterns within data (Braun and Clarke 2006), whereby the patterns are coded until themes are generated (Fereday and Muir-Cochrane 2006). A code is produced when the researcher has identified something of interest or importance within the raw data (Boyatiz 1998), this is done by ‘tagging’ and naming selections of text (Braun and Clarke 2006, p.86). Themes are generated when a visible pattern is identified within the generated codes, themes then help the researcher to address or understand the topic of the research (Boyatzis 1998). Within this approach there are various levels of analysis (semantic and latent). A semantic approach focuses on one level of analysis where the researcher does not delve into the data above and beyond ‘what has been said or written’, whereas latent levels of analysis means that the researcher explores beyond the data to search for meanings above and beyond ‘what has been said or written’ (Braun and Clarke 2006, p.84).

Methods of data collection:

- Observation
- Video and audio recordings
- Interviews
- Likert Scales (asked during interview stage)

In order to manage, organise and analyse the data, the management software system **NVivo 12** was used. Within NVivo two main types of terminology are used to describe the data and

how the data are managed (sources and nodes). Sources refer to the data collection method, for example observation, and nodes store coded data to begin the process of developing and managing themes Prior to using NVivo in this research two training workshops were previously attended by the researcher on two occasions (hosted by Ben Meehan).

Triangulation in line with Braun and Clarke's (2006) coding scheme, is where the nodes are collated and gathered to search for potential themes and where the developed themes were reviewed. As discussed in the first section of chapter four, multiple method triangulation will be used to gain further insight into the data. This allows individual data sets to come together, forming one overarching data corpus adding validity to the findings if similar patterns were visible across more than one data set. At this stage we started to search for potential themes (phase four). All the raw data was reread and reviewed to ensure that the data was representative of the node and theme within which it was placed. After further refinement, key initial themes were identified, which were collapsed into refined main themes.

Whilst this is a in depth guide, our results/aims do not require a massive amount of analysis; this strategy should be used as a guideline, but analysis does not strictly need to follow this exact route or depth.

Step by Step Guide

- So, for the most part we are applying themes and reoccurring ideas to what we already know
- This gives us a good understanding on answers to our questions
- However, we also have a decent idea of where to go to next; through this thematic analysis and deductive reasoning we will confirm this direction and generate more insights
- So, this research currently is mixed methods; qualitative = case studies whereas quantitative = experimental studies which fall in line with a pragmatic approach
- Our method is thematic analysis in which we use mostly deductive reasoning with some inductive reasoning.
- Semantic view (i.e., explicit – people said this, they mean exactly that)
- Research Design: pragmatic (we have an issue; we solve it with fact & real solutions)

STEPS:

Phase 1 – Familiarisation with the data will involve transcribing data, reading, watching and listening to the initial data whilst noting down general ideas and key takeaways

Phase 2 – Creating initial codes involves coding interesting features and observations of the data and then identifying patterns/themes within this data (a basic coding)

Phase 3 – Themes will involve breaking down the now restructured codes into themes & sub themes to offer more in depth understanding of the highly qualitative aspects under scrutiny such as divergent views, negative cases, attitudes, beliefs and behaviours coded to these categories and to offer clearer insights into the meanings embedded therein

Phase 4 – Review Codes & Themes will involve consolidating themes into a more abstract and conceptual map of a final framework of codes for reporting purposes. Categorising all themes into umbrella ones which relate to the aims of the study as well the research aims

Phase 5 – Writing Analytical Memos against the higher-level codes to accurately summarise the content of each category and its codes and propose empirical findings against such categories. These memos will consider 5 key areas:

1. The content of the cluster of codes on which it is reporting
2. The patterns where relevant (levels of coding for example although this could be used to identify exceptional cases as well as shared experiences)
3. Considering background information recorded against participants and considering any patterns that may exist in relation to participants' profiles
4. Situating the code(s) in the storyboard –meaning considering the relatedness of codes to each other, and their importance to addressing the research question and sequencing disparate codes and clusters of codes into a story or narrative which is structured and can be expressed in the form of a coherent and cohesive chapter
5. Considering primary sources in the context of relationships with the literature as well as identifying gaps in the literature

6. Phase 6 – Validation will involve testing, validating and revising analytical memos so as to self-audit proposed findings by seeking evidence in the data beyond textual quotes to support the stated findings and seeking to expand on deeper meanings embedded in the data. This process involves interrogation of data and forces the consideration of elements beyond the category itself, drawing on relationships across and between categories and cross tabulation with demographics, observations and literature. This phase will result in evidence-based findings as each finding must be validated by being rooted in the data itself and will rely on the creation of reports from the data to substantiate findings.

7. Phase 7– Producing a report involves analytical memos into a coherent, cohesive and well supported outcome statement or findings report. Finalising the analysis will result in having produced two draft chapters: namely the findings and discussion chapters.

Analytical Process (Data Analysis Guidelines)	Practical Application in NVivo	Strategic Objective	Iterative process throughout analysis
1. Comparing units of meaning across categories for inductive category coding	**Phase 1** Familiarisation	**Descriptive Accounts** *(Reordering, 'coding on' and annotating through NVIVO)*	Assigning data to refined concepts to portray meaning
2. Refining categories	**Phase 2** Initial Coding		
3. Exploring relationships and patterns across categories;	**Phase 3** Coding on *Define Themes*	**Data Management** *(Open and hierarchal coding through NVIVO)*	Refining and distilling more abstract concepts

4. Integrating data to write findings	**Phase 4** Review Themes **Phase 5** Writing *analytical memos* **Phase 6** Validation **Phase 7** Synthesising *Data* *Report Writing*	**Explanatory Accounts** *(Extrapolating deeper meaning, drafting summary statements and analytical memos through NVIVO)*	Assigning data to themes/concepts to portray meaning Assigning meaning Generating themes and concepts

Table 1 now sets out the Stages and Process involved in Qualitative Analysis as set out in this strategic memo and relates them back to the study's methodological and philosophical underpinnings using the data analysis guidelines

B.2 Music Game Inspirations

64.0
140
#Funtime
0D Beat Drop
A Dance of Fire and Ice
Aaero: Complete Edition
Active Neurons
Akihabara - Feel the Rhythm
AUDICA: Rhythm Shooter
Audio Surf
Audioshield
Auditorium
AVICII Invector
AVSEQ
Bad Hotel
Baila Latino
Band Hero
BandFuse: Rock Legends
Beat Hazard
Beat Rush
Beat Saber
Beat Sneak Bandid
Beatbuddy: Tale of the Guardians
Before the Echo
Bit.Trip Beat
Bit.Trip Core
Bit.Trip Fate
Bit.Trip Flux
Bit.Trip Runner
Bit.Trip Void
BoxVR
BPM: Bullets per Minute
Britney's Dance Beat
Bullet Beat
Cadence
Cadence of Hyrule
Cello Fortress
Chime
Chiptune Runner
Chroma
Cinnamon Beats
Circadia
Circuits
Cosmic DJ

Crypt of the NecroDancer
Cytus Alpha
Dance Central
Dance Collider
Dance Dance Revolution
Dark Witch Music Episode: Rudymical
DEEMO
Def Jam Rapstar
DJ Hero
DJMax Respect
Double Kick Heroes
DubWars
Dyad
Eat Beat Deadspike-san
Electronic Super Joy
Elite Beat Agents
Eloh
Energy Invasion
Every Extend
Everyday Shooter
Fishjn'
Fitness Boxing
Floor Kids
FRACT OSC
Frederic: Resurrection of Music
Freedom Finger
Frequency
Fuser
Gal Metal
Geometry Dash
Groov
Groove Coaster
Guitar Hero
Gun Jam
Hatsune Miku VR
Hexagroove: Tactical DJ
Hide & Dance!
Incredibox
Inside My Radio
Intralism
JAM Live Music Arcade
Just Dance
Just Shapes & Beats
Karaoke Revolution

Kingdom Hearts Melody of Memory
Let's Sing
Lofi Ping Pong
Lumines
Major Minor's Majestic March
McOsu
Melodive
Melody's Escape
Michael Jackson: The Experience
Musaic Box
Muse Dash
Music Killer
Music Racer
Musynx
My Singing Monsters
Neon Beats
Otocky
Overpass
Panoramical
PaRappa the Rapper
Patapon
Pistol Whip
PixelJunk Eden
Project Arrhythmia
Pugs Luv Beats
Quaver
Racing Pitch
Radio Flare
Radio Squid
Radiohammer Station
Rez
Rhythm Doctor
Rhythm Fighter
Rhythm of the Gods
Rhythm Tengoku
Rock Band
Rocksmith
Rolling Sky
Sayonara Wild Hearts
Sentinel
Sentris
SingStar
Songbird Symphony
Sound Shapes

Space Channel 5
Spice World
Spin Rhythm XD
Super Beat Sports
Super Dodgeball Beats
Symphony
Synth Riders
Synthesia
Taiko no Tatsujin
Tapsonic Bold
Thumper
Tone Sphere
TouchMix FX
Track Lab
Vectronom
Vib Ribbon
VOEZ
Wandersong
Wave Trip
Wii Music

UPCOMING/INSPIRATION:
Evertried
Backbeat
Refactor - an idea for music creation more than anything else