Investigating dynamic terrain as a novel mechanic to solve puzzles in games within a real-time physics simulation context



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# Abstract

Modern video games tend to rely heavily on the work of their physics engines, software that helps to compute components such as collision detection, particle systems and, more recently, terrain deformation. However, terrain deformation typically hasn’t seen much application as a core component of commercial games, so this project aimed to investigate the use of this dynamic terrain modelling to solve puzzles in a video game. This project explores the development of this game using the *Unity* game engine, with its inbuilt implementation of the *PhysX* physics middleware, and documented how players responded to this novel application of terrain deformation as a puzzle solving mechanic. From a study involving 8 people, it was discovered that they enjoyed the concepts involved in the game…

# Background

As computational resources available continue to grow, games developers set their aims on implementing more facets of the physical world into their creations to heighten realism, this is where the idea of reproducing real-world physics into games came about. The usage of rudimentary physics simulation in games can even be dated all the way back to *Pong* with it’s simulation of a ball bouncing off walls and paddles, while this may seem incredibly simplistic by today’s standards it laid the groundwork for the vastly more complex systems we have now.

The demand for more elaborate physics simulations in games grew, this lead to the creation of dedicated physics middleware, engines devoted to the accurate and realistic simulation of physics in real-time. As of today, the most widely used and richly featured physics engines in the games industry are Microsoft’s *Havok* and Nvidia’s *PhysX*, *Havok* being the most popular choice among developers with over 400 games using it in some capacity (Havok, 2011). However, most modern physics engines all feature similar physics techniques that developers can then implement in their games, these can include:

* Rigid Bodies: A simulation of how solid objects are structured, which can then have Newtonian mechanics applied to them to model their motion.
* Collision Detection: A system of calculating whether two objects have collided (typically using a bounding volume) and determining an appropriate response.
* Ragdolls: A way of procedurally animating characters within a game to give them realistic movement and interact with the environment in a natural way.
* Particle Systems: A controllable set of individual physical particles that react to external forces and, in some instances, forces between each other. These are used to model things such as water, smoke, cloth and rain.
* Deformable Bodies: Giving objects the ability to either shatter, destruct or deform

This concept of deformable bodies presents a great many possibilities in how a game world can be impacted upon by the actions of the player as, while some methods to model bodies of this nature can be rather computationally expensive, it creates a much more accurate depiction of how objects behave in the real world.

The concept of presenting a puzzle to the player, which they then must solve with the mechanics available to them, has been a staple of video games for decades. Whether the puzzles define the core of the game, such as titles like *The Witness* (Thekla Inc., 2016), or they form small challenges along the way like in the *Uncharted* games (Naughty Dog, 2007), games developers are always searching for new and unique ways of testing a player’s problem-solving abilities.

The original aims and objectives from the project proposal were as follows:

* Aim:  
  To experiment with the concept of deformable terrain, using a real-time physics simulation context, as a novel mechanic to solve puzzles in a game. The impact of this mechanic in gameplay, how it affects a player’s perception of puzzles and how they can solve these puzzles using the tools at their disposal.
* Objectives
  + To investigate and experiment with the current implementations of physics systems and middleware to find a suitable basis to build a real-time solution for terrain deformation, such as *PhysX* and *Bullet*. Additionally, to explore ways to implement this system into a game, potentially through existing games engines like *Unity* and *Unreal Engine*.
  + The game should go through an extensive design and prototyping process to ensure that it delivers an enjoyable and coherent experience for the players, with focus on conveying the mechanics and how they operate clearly.
  + To successfully develop the game into a functioning prototype, demonstrating the implementation of terrain deformation that responds in an appropriate real-time context to the player’s interactions with it. The game will be designed with this player-controlled terrain deformation in mind as the primary tool for solving puzzles.
  + To evaluate the effect that using dynamic terrain as a game mechanic has on the gameplay experience and how it influences their approach to puzzle-solving. To do this the artefact will need to be presented to a group of play-testers to investigate what their experience with the concept was like, what components they enjoyed, and which features they gravitated towards, along with more quantitative data from logging their interactions with the game.

These aims & objectives provided a guideline for key areas that needed to be investigated for the outset of this project:

* Physics Simulation
  + As the focal point of this project, it is vital to explore the existing academic investigations into the subject of how to simulate physics in real-time, the various ways in which this can be achieved, the benefits and drawbacks of these implementations and then finding one that appropriately fits the scope of this project.
* Game Design
  + To justify the approaches made with regards to the design of the game produced for this project, existing literature that provides a framework of how to approach the design stage of this kind of artefact production, whilst also being sure to consider the focus that should be placed upon the deformable terrain aspect.
* Puzzles in Games
  + As this project focuses not only on the implementation of deformable terrain but also how it can be applied to puzzles, it is key to research the techniques employed in designing these puzzles, presenting them to the player and to place a focus on the deformable terrain mechanics the player will be using to solve them.
* Player Experience
  + It is important to consider the ways in which the artefact produced for this project would be evaluated regarding the aims and objectives laid out above. Therefore, appropriate research methods for evaluating the response of players to the various aspects of a game will need to be investigated.

# Literature Review

Following on from the aims and objectives laid out prior, and the subsequent areas highlighted for investigation, the following academic literature has been explored and evaluated in the relevant areas.

## Physics Simulation

Due to the heavy focus that this project places on the area of real-time physics simulation, it was vital to investigate existing academic applications of physics systems, what they are used for, how they are implemented, and any other important academic discoveries made in this field.

An important first step in exploring the domain of physics simulations, especially their implementation in video games, is to gain an appreciation for the background on how these systems have changed over the years. In Árnason’s exploration of the evolution of physics in gaming (Árnason, 2008) he found that, while physics have played some part in games since their inception, it is not until the advent of more realistic physics simulations that they have come to the forefront of the experience. Through this investigation it has become clear that these complex physics engines are now integral to modern video games, as they provide key functionality such as collision detection and several types of body modelling (rigid, soft and deformable). However, due to the rapid advancements in GPU technology, the concerns that this paper raises in terms of the computational cost of physics simulations are now somewhat alleviated. While the most accurate simulations of complex dynamics are still very difficult to simulate in real-time, the approximations that most video games now use are handled easily by the GPU (especially given *Nvidia*’s assimilation of *Ageia* and the *PhysX* engine). This paper therefore grants a useful reminder of how far real-time simulations of physics have come in a relatively short time, to the point where they are now integral to the functionality of many games, framing the work of this project as a continuation into the exploration of how physics in games could continue to evolve.

Many of the more prevalent studies that, not only investigate real-time physics simulations in general, but place a focus on how to model deformable terrain tend to take a serious approach in terms of its application. For instance, the modelling of soil deformation in real-time to use in virtual reality training simulators for tools such as bulldozers and excavators, where a sufficient level of accuracy is required to deliver a reliable training experience for the users (Holz, Beer and Kuhlen, 2009). This study places the focus on implementing complex equations and calculations to deliver the most realistic behaviour of soil deformation, featuring both erosion and compaction. The issue with studies of this nature is that the onus is on this computationally expensive accuracy, which is not something that could be afforded in a project such as this where there are limited resources available, both in terms of hardware and time. These types of papers do still hold some value for this project however, as they present a good idea of how terrain deformation could be approached but with some simplification changes to the modelling to alleviate some of the computational expense.

It is also key to investigate potential methods of implementing deformable terrain in a real-time context, one academic paper explored this through the visualization of tire tracks on large scale dynamic terrain (Zhang et al., 2010). In this paper, the academics took the approach of using a GPU-based terrain deformation algorithm to compute the alterations caused to the terrain as a result of a vehicle in the scene. This implementation utilised a custom algorithm in conjunction with heightmaps, then passing this to GLSL shaders and rendering the scene using OpenGL. Having such a specific implementation allowed them to achieve a very high frame-rate for the simulation, making it suitable for a game application, which could prove useful for consideration of what tools to use for the development portion of this project. However, it may be important to consider the other aspects that will be required in the artefact’s development other than this purely physics simulation-based approach.

In *Alternative Trajectories* (McKeown, 2016) McKeown analyses the impact that the physics engine has on a first-person shooter videogame, in this case *Call of Duty: Ghosts*. With this paper he outlines how the game prioritises its realism through a fairly accurate approximation of Newtonian physics, shaping the players’ actions through its implementation. The noted functionality of this game’s physics simulation includes a set of complex physical effects, such as smoke, where the effects respond to the player and other objects in the scene. However, the key focus was on how the game’s physics interprets gravity, especially regarding how players can adapt their gameplay techniques to take advantage of the systems available to them to create novel gameplay moments (such as throwing a knife into the air, anticipating its arc of movement due to gravity and aiming to eliminate an enemy player). When considering the goals of this project, the most important takeaway from this paper is what drives players to experiment with physics systems in this way and how we can foster this gameplay behaviour. It appears that the best way to achieve this is to make the behaviour of the game systems explicit to the player, ensuring they understand exactly how they behave and thereby allowing them to take matters into their own hands when playing around with them.

Another important consideration to be made with physics simulations is how they can be understood by the people playing it, as the simulation needs to make coherent sense with a player’s personal understanding of how physics works, a subject that was explored by academics looking into cognitive science (Ullman et al., 2017). Here, the academics explored the parallels between the features of physics engines and how humans represent physics in their head, placing a focus on the intuitive physics of infants and how this develops. Throughout the course of their study, they outline the key features of game physics engines and compared this with how people interpret the physical world around them, noting that there is a convergence in the need to overcome resource challenges in both instances and finally offers new hypotheses as to how intuitive physics could be used in the development of artificial intelligence. This study provides useful considerations in terms of how best to structure and present the physics systems at play in the artefact in this project to ensure that they make immediate sense to the people playing it.

One of the most valuable applications of physics systems is their ability to aid the learning of students, as it provides a safe and infinitely variable way of experimenting. These physics simulations, especially those that were originally developed for use in commercial video games, are typically richly featured and can be used to model typical physics experiments, which was the focus of a 2008 paper (Price, 2008). In this study, the physics engine of *Unreal Tournament 2004* was utilised to demonstrate various forms of physics experiments such as the interference of waves and parabolic motion due to gravity, motivated to encourage younger students to learn and develop an interest in physics. Through extensive experimentation with both students and their teachers, they found that both parties found it straightforward to construct experiments using the game physics engine, the qualitative experiments developed using the software had a definite impact on the students’ learning experience and that the theory of ‘concept maps’ provided a valuable design methodology. This provides a valuable knowledge base for this project, as it demonstrates an intuitive understanding that users have when interacting with a virtual environment that successfully emulates real-world physics concepts, such as gravity. Knowing this ensures that, so long as the physics system and related mechanics within this project’s game fit with generally understood concepts in physics, players should confident in experimenting with the tools and understanding what impact will be made on the world.

Another way in which physics concepts can be simulated to assist teaching is through their application within a serious game setting, where the educational content is fed through the gameplay, elevating the software beyond pure entertainment. For academics, this means studying the impact of these serious games based around physics on a student’s learning, with one such study looking at teaching high school physics (Stege, Lankveld and Spronck, 2012). In this work, the academics placed their focus on the effect of serious games on teaching electrical engineering to high school students, comparing this to those taught via text. They evaluated this through a phase of testing where, after students had either played the game or read the text, they would be tasked with solving assignments, which was then followed by a survey. From their results, the researchers found that the use of a serious game had a positive impact on the learning of male students compared to female students, though they found that female students who played the game felt less motivated than those who read the text. The reasoning for this was left undetermined, but they concluded by noting that serious games have the potential to be a more effective education tool than textbooks, particularly for male students. While the game being produced in this project is not of a serious nature, the ability to successfully convey physics behaviour to the players is crucial for understanding the mechanics of the game. It may therefore be useful to note the ways that the serious game in this study attempts to relay knowledge of physics to the players, as this could prove beneficial for the game design of this project.

## Game Design

Due to this project’s focus on creating a game to encourage fitness, it was also imperative to investigate the area of game design, the use of components of games and frameworks for their design.

When considering how to approach designing a game, it can be valuable to make use of pre-existing frameworks produced and reviewed by academics, with one of the most ubiquitous being the MDA Framework (Hunicke et al., 2004). This framework places an emphasis on both how the player and the designer interact with the game, be it from alternative perspectives where the designer focuses primarily on the mechanics whereas the player focuses on the aesthetics. This framework provides a good basis for how to approach game design, as it serves to remind the designer that players will first be drawn in at the surface level to the game before they delve deeper into how the game works. By having these abstracted layers, the MDA framework helps to tackle iterative design, allowing the designer to tweak certain aspects of the game to obtain the desired player experience, this therefore could make MDA a useful tool for the designing process of this project.

Another important consideration in the design of games is how to link all of the various software that makes it up and presenting it as a cohesive whole to the player, this process has even seen the development of a framework in this academic field (Catanese et al., 2011). In this paper the researchers combined multiple cutting-edge games middleware, including the *PhysX* physics engine, and integrated them together using *Direct3D* and *OpenGL* for graphics. The focus with this study was on how to produce a dynamic 3D environment that features a greater degree of realism through the use of these various middleware technologies, aiming to simulate how the objects in the world behave and how they can interact with each other. While the focus on delivering a wholly realistic and complex world may not in itself be vital for this project, the techniques through which they successfully allow these tools to work together may be worthwhile to consider, as it may help to ease development later in the development process.

## Puzzles in Games

The primary component to the game artefact produced in this project’s artefact, other than the terrain deformation, is the production of puzzles that the players can use the game mechanics at their disposal to solve. It therefore seemed necessary to examine the existing material regarding the design and importance of puzzles in games.

Much like with traditional game design that aims to structure the entire game, there are also many design principles that go into the production of both puzzles in games and puzzle games themselves, this being something that applies to real-world puzzles and digital puzzles alike. One paper investigated these principles of puzzle design (Zhou and Wu, 2012), particularly looking at the integration of educational content in these puzzle games and how they can be used to aid learning. They broke the requirements of these puzzles down into aspects of content, manifestations, human-computer interactions and feedback, then outlining the principles that need to be followed in these different categories. While this paper takes an overtly serious approach due to it’s connection to aiding education, the design process they lay out still has a great relevance to the desired aims of the puzzles produced in this project, it may therefore prove useful to refer back to this study during the design process of the game’s development to aid the structure of the puzzle design aspect.

One study looked at how puzzle games can be thought of as a metaphor for computational thinking (Law, 2016), where people go through a process of implementing sequence, selection and iteration. Throughout this paper, Law explores the links between puzzle-based learning and the concepts of computational thinking, making a case that puzzle games could prove to be a valuable tool for teaching programming, as they provide an environment for developing the players’ problem-solving skills. From here he then gives examples of existing educational and commercial games that foster these problem-solving abilities, with the educational games delivering a more overt demonstration of computational processes whereas the commercial games have these processes occurring in the background. The commercial games chosen here, namely *Portal*, *The Talos Principle* and *World of Goo*, provide valuable examples of how both physics and puzzle solving can be united to creating interesting and valuable game experiences. This paper therefore provides useful reference material for existing implementations of puzzles and physics in games for consideration of how to design the artefact for this project, while also providing a framework of how to consider the design of puzzles in terms of computational problem solving.

Another paper looked at how typical puzzle design doesn’t go far beyond visual cues, taking advantage of this to experiment with new puzzle challenges using other sensory information, such as through sound and vibrations (Carvalho, Duarte and Carriço, 2012). From the results they obtained, they discovered that players tended to solve the most prominent areas of the puzzle first and would then leave the more abstract regions to the end, this proved to be true regardless of the interaction modality used, be it audial or visual. This could prove to be a valuable consideration when designing puzzles, to provide the players with a more prominent problem to solve first before they can tackle the more challenging aspects, which could then be observed as people play the game to see if they tend towards this approach.

One of the key components to many puzzle games is that there are typically many different techniques that the player can employ to solve the puzzle, this can provide a fascinating research point as it can help us to understand how players learn skills in games and then apply this to solve problems. In a paper focused on these puzzle-solving tactics (Vahdat, 2016), the academics applied Learning Analytics in puzzle games to explore the players’ approach to puzzles and how they applied skills that they learnt in the game. Through their research process, the academics presented a three-step analysis to retrieve the puzzle-solving tactics of players from data, allowing them to identify tactics not considered by the game designer. Their Learning Analytics approach proved successful as they discovered two main successful tactics, so this could be valuable asset in evaluating the techniques that players employ in playing the artefact of this project should sufficient data be collected, though it presents a good example of puzzle game study design regardless.

## Player Experience

When it comes to the evaluation side of this project, it became swiftly clear that devising an entirely original system of questionnaires and interviews would prove to be somewhat of an insurmountable task given the time and resource constraints of this endeavour. However, there already exists a vast range of academically ratified games evaluation materials, therefore this required exploration to determine the best fit for this project.

Due to the proliferation of player experience research and the development of surveys to monitor this information, it is therefore paramount to find a way of determining which of these standardised questionnaires are most appropriate for the research being carried out. In an evaluation of the currently available methodologies for measuring player engagement (Nordin, Denisova and Cairns, 2014), academics found that there is a certain degree of overlap between many of the existing questionnaires in what components of user engagement they are measuring. Knowing this, it is therefore important to ensure that the survey used in the evaluation of this artefact fulfils all the appropriate criteria and that no unnecessary overlap is created in the event of multiple different surveys being used concurrently.

One such evaluation strategy comes in the form of the *Game Engagement Questionnaire* (Brockmyer et al., 2009), a way in which players’ engagement in a video game can be measured through the application of a survey. In the development of this survey, the academics highlighted the key components of presence, flow, absorption and dissociation, which define key states of being while a player is engaged in a game. Through their development and evaluation, the academics found that the Game Engagement Questionnaire provided a psychometrically strong measure of the player’s engagement levels while playing a game, which they highlight as being invaluable for examining factors for the negative impact of games. While in this project we won’t be investigating this impact, the measurement of player engagement that this survey affords could prove to be useful in evaluating this project’s artefact.

Another example of a standardised post-game survey can be found in the *Game Experience Questionnaire* (IJsselsteijn et al., 2013), a survey that utilises a modular structure that can be adapted depending on the evaluation requirements of the study being conducted. This questionnaire presents a straightforward methodology for administering a set of questions designed to learn about certain aspects of the players’ experience, such as immersion, challenge, flow and competence. The modular nature of this questionnaire makes very suitable for a project of this scale, as it allows the questions to be focused and speeds up the evaluation process.

It’s also valuable to investigate how established research studies carried out their evaluation in practice, one such study investigated the effects that the game *Portal* had on players’ physics intuitions and spatial cognition skills (Adams, Pilegard and Mayer, 2016), resulting from the Newtonian physics simulation in the game. In this study, participants were measured on their performance through tests on their retention of physics knowledge that they may have gathered from their experience in the games they were asked to play. While they found no concrete evidence that playing these games facilitated the participants’ physics learning, this study still provides a good example of how to conduct a games research study in terms of structure and data collection.

Another important realm of study to research was that of how to analyse the data that would be collected in the evaluation phase of this project, especially given the elicitation of qualitative data in this stage. One such approach to analysing this type of data is ‘Thematic Analysis’, a form of qualitative data analysis that focusses on identifying, examining and denoting patterns within the data; this technique typically finds application in the fields of psychology, but it can be applied in a vast array of fields. The problem with thematic analysis is that it is typically poorly laid out, leading to confusion over how to properly apply it, this is where work in the field of psychology comes in (Braun and Clarke, 2006). In this paper, Braun and Clarke outlines the key aspects of thematic analysis, generating a table of different phases and a 15-point checklist of how to determine good analysis. This therefore will provide a vital tool for carrying out the analysis side of the research further in the project, as qualitative data is likely to be key in evaluating the success of this project in its aims and objectives.

# Methodology

## Project Management

The paramount factors when considering how to manage a project of this type is the limited resources available, both in terms of time and manpower, as it is entirely the work of an individual over the course of just a few months. Therefore, it was vital to break down the project into distinct and measurable components to more appropriately structure the process. As this project is comprised of both artefact development and evaluation through research, the key components highlighted were: Background Research, Designing, Development, Artefact Evaluation and Documentation.

Regarding how best to manage a project, a range of different management techniques were investigated to determine which of the existing methodologies would best suit the needs of this project. Chief among these strategies is that of PRINCE2, the UK government standard for managing information systems projects. Upon investigation of this methodology however, it soon became clear that it would be inappropriate for a project of this scale. The reasoning for this is that, while there claims to be a degree of scalability to the PRINCE2 methodology, the amount of paperwork it demands would eat up a considerable amount of time, which would raise an issue with the strict time limitations of this project. Despite this, this methodology still proved to be useful to investigate, especially with regards to context of how larger scale software development projects may operate in the UK technology sector.

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In practice however, the exact methodology of how to manage the project was often overlooked in favour of simply tackling challenges piece by piece and when they arose.

The methodology that was finally chosen as the basis for this project was a tweaked version of the agile method. This method was selected as it offered the most flexibility out of all those investigated, which was an invaluable characteristic as, due to the individual nature of this project, it would need to continually adapt along the way. This methodology was recently analysed in *Analyzing Agile Development – from Waterfall Style to Scrumban* (Stoica et al, 2016), where they outlined that agile development allowed for tasks to be executed quickly and easily be adapted when needed. This was especially important for this project as, due to the nature of this project being undertaken alongside other pieces of work, some aspects of the project needed to be able to change on the fly (especially the timeframe on which tasks were planned on being completed and the actual tasks that need completing).

The 5 components of this project were discerned in the Gantt chart produced in this project’s proposal. This chart proved invaluable when trying to chart the progress of the project and whether the various tasks that were outlined were being completed on time. However, over the course of carrying out the project, the timeframes of some sections lined out in the original Gantt chart meant that some tasks would’ve ended up being incredibly difficult to complete to a reasonable level in the time. This meant that the Gantt chart saw several iterations as certain tasks required more and some required less time to complete. The original Gantt chart can be seen in Figure 1, and the final variation of it can be seen in Figure 2.

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Figure : Original Gantt Chart

**  
^ Figure 2: Final Altered Gantt Chart**

Clearer versions of the above Gantt charts, along with the related list of tasks that comprise the Y axis, can be found in Appendix 1. While the Gantt chart provided a good visual representation of how the project should pan out in the initial stages, it soon became clear that, in reality, there are unforeseen occurrences that disrupt the course of events and impact the timeline. For instance, the work of other university assignments demanded more time than anticipated which meant that certain parts of the project needed to be put on hold until the other assignments were completed. Additionally, some tasks laid out at the start ended up taking less time in practice than originally anticipated while others took longer, this therefore meant that the original Gantt chart lost its relevance soon into the project. To compensate for this, amendments were made to the initial Gantt chart along the course of the project to give a more up-to-date impression of how the project was shaping up.

Larger versions of the charts, along with the list of relevant tasks, can be found in Appendix 1. This changing nature of the chart allowed it to be more versatile, however this raised issues of having a set project schedule to stick to. Additionally, some tasks needed to be changed during the project, for instance the task to implement a leaderboard system was completely scrapped due to it not being a particularly viable feature on the smartwatch hardware platform as a result of the limited screen size and unlikely connection to the internet when walking about outside.

## Software Development

A methodological analysis of software development approaches used should be included, taking into consideration the characteristics of the software being developed and the computer environment requirements. Once again, be sure to support the chosen methodology with appropriate, recent academic references.

You may want to give thought to how you collected the requirements of the software being developed, did you collect data from people, use academic literature or some other way.

Do not simply discuss software development or explain how typical methodologies work (spiral, waterfall, etc.)

## Toolsets and Machine Environments

Outline the tools for both software development and project management, make appropriate comparisons between the tools available and argue for the most appropriate selection.

Do not justify the grounds for using certain tools simply on prior experience or skills developed.

Discuss possible machine environments under which the artefact may be required to operate and, through analysis, comparison of features and possible user requirements, a determination of the chosen environment(s) will be made.

Tools for project management

* Microsoft Excel
* Google Calendar

Tools for software development

* GitHub
* Physics Engines
  + PhysX
  + Havok
  + Bullet
* Games Engines
  + Unity
  + Unreal Engine

For the project management component of this project, the key factors that influenced the selection of the tools used was the availability of the tools and their accessibility in a range of scenarios. For instance, Google’s Calendar tool was used extensively for setting goals, milestones and deadlines throughout the course of the project as it is available anywhere, so long as the user has some form of internet connection. Additionally, through connected functionality with a modern smartphone, notifications and alerts can be set to pop-up at certain times to remind the user of various events, which proved invaluable for setting deadlines on getting certain aspects of the implementation completed and ensuring that this personally set goal was not forgotten.

One tool that provided uses for both project management and software development, is the versioning tool *GitHub*. This not only provided a way to continually back up the code implementation of the project, meaning that every step along the development process was saved as a version so that, if any part of the code broke irreversibly, an earlier working version of the code could then be accessed.

With regards to the software development side of this project, there were some vital components that needed consideration. Chief among these was how to appropriately model the desired physics in the produced artefact, as there are many approaches that could be taken. One way in which this could be achieved is to produce the physics functionality independently, using a dedicated SDK of an existing physics engine middleware such as *PhysX* or *Bullet*, then using a graphics engine on top of this to present a visual component to the player, such as *OpenGL*.

Another important consideration was in which physics engine to use, as there are a number of well documented products on the market, with the most prominent of which being the aforementioned *PhysX*, *Havok* and *Bullet*, though each of these engines has their advantages and disadvantages. *Havok* for instance, while it is by far and away the most popular dedicated implementation in the video game industry, it is also closed-source, requiring the developer to be accredited and to pay an expensive fee to license its usage. This therefore meant that the use of *Havok* would be off the table for this project, as it is a limited production with a relatively small amount of resources available. *Bullet* on the other hand is entirely open-source and freely available, while still maintaining a rich feature-set of physics techniques, such as rigid & soft body simulation, collision shapes and even deformable objects. However, the issue with *Bullet* arises when trying to build a complex game system around it, as many of the existing solutions using it are not as richly featured or conducive to a project of this nature. This is where *PhysX* comes in because, as of *Unity 5* and *Unreal Engine 4*, *PhysX* has been built into these industry standard game engines by default as the underlying physics engine running the simulations.

## Research Methods

In terms of evaluating how successful this project has been in its aims and objectives, research was determined to be a key component of this project.

* It was determined that both quantitative and qualitative data would be collected in this study.
  + This was chosen because it would give a good balance of information regarding how the play sessions went measurably and how the players deemed their experience.
* For this, the quantitative data should be collected through in-game metrics and logging, giving an overall view of how players interact with the game on a technical basis.
* Qualitative data will be collected through post-game interviews and surveys, to gain a more nuanced view of how the players thought of their experience playing the game, especially with regards to the terrain deformation mechanics central to this project.
* In terms of representing these results:
  + Much of the quantitative data can be presented in graphs and tables, give an overview of how players interacted with certain aspects of the game (how long they took, how many times they reset and how much they experimented with using the mechanics)
  + As the qualitative data takes the form of more longform answers, these will be transcribed and typed up, with excerpts that help to answer the research question being highlighted and investigated

To evaluate how successful this project’s game is in its goals, it needs to be judged in how well it encourages users to engage in physical fitness. For this the smartwatch and game were given to volunteers who engaged in a short-term test, in this test they were asked to use just a basic step tracker for 3days and then to use the game to track their steps for the same amount of days. At the end of each day they were asked to note down how many steps they had taken that day according to the relevant application they were using. Examples of the consent form the users were presented with and the testing diary that they were asked to fill in can be found in Appendix 4 and Appendix 5 respectively. Additionally, the collated data from these user tests can be found in Appendix 6, to visualise this information the following Figure 5 and Figure 6 show the users’ engagement with the standard tracking app and the game produced in this project.

**Figure 5: Standard Step Tracker Use**

**Figure 6: Game Step Tracker Use**

As these figures show, in general, most users displayed a noticeable increase in the number of steps they took when using the game to track their steps over the traditional step tracking app. This potentially shows that the application of gamification to fitness in this case has helped to encourage users to engage in physical activity. However, as the graph shows, there are noticeable signs that some people were quickly diminishing in their number of steps taken even when playing the game. This could highlight the issue that research found where encouraging sustained use of these kinds of applications is difficult to achieve, so further iteration may be needed to ensure this.

There were some notable comments that testers made over their time with the device and use of the applications, one of which being that the continual need to recharge the smartwatch at the end of each day soon became a bit of a chore and was far from convenient. This highlights a key issue with the very hardware that this software was designed for, in that it simply doesn’t factor smoothly into consumers’ daily routines and that adding another device that users need to worry about keeping charged may deter them from using the hardware altogether. Another important note that testers made was that, although the game had them engaged at the beginning, they soon felt like they’d experienced most of the mechanics at play and were not sure whether they would’ve continued to keep playing much longer after the testing period. Therefore, to combat this in future, a greater breadth of varied content will need to be produced to make players feel like they’re always discovering something new. Perhaps the use of procedural content generation with the way in which encounters work and what kind of enemies the player comes across feel like to play against.

Due to the scope of this project being primarily that of development and implementation rather than research, the limitations of time and testing hardware available, the data-set used is rather small in this instance. This is more to gain a rough insight as to how successful the solution presented here appears to be to people who have had no previous interaction with the project. If this project did indeed have a larger research scope of investigating the efficacy of gamification in smartwatch fitness apps, it would be better to test a far greater and varied group of test subjects in order to gain more insight into the specific instances where it is effective and where it falls short.

# Design, Development and Evaluation

As the aims and objectives laid out for this project demanded both the development of an artefact as well as the evaluation of said artefact, it was imperative to approach these components in a careful and thorough manner.

## Software Development

For the software development component of this project, there were key aspects of the development process that could be separated out into various distinct tasks.

### Requirement Elicitation

The foremost step in the software development section of this project was to determine what the requirements of the final artefact would be, as there is no client to speak of, these requirements were defined by research question we are looking to answer. In this case, our primary area of interest was the implementation of real-time dynamic terrain and using this to solve some sort of puzzle in a game. Therefore, the basic requirements for this artefact were to produce a game that presents the user with a selection of puzzles to solve, with the primary mechanic available to them being the ability to deform the terrain in the level, so there needed to be some degree of real-time physics simulation to model this.

* How the target demographic was chosen
* Create a user scenario

### Design

The next step in the process of development was to design the game itself, in order to facilitate this a game design document was produces [Appendix ?]. This document sets out the core gameplay experience that the player is intended to have, the flow of the game, the mechanics that should be at the players’ disposal and the intended solutions to the puzzles in the game.

* This sets out the core gameplay experience that the player is intended to have
* What mechanics the player has available to them at each stage of the game
* The intended solutions and pathways through the game
* The various stages in the game

### Coding

Due to the usage of Unity in this project, the choice needed to be made between which of the engine’s supported languages to use, C# or JavaScript. While Unity provides documentation for the vast array of its features using both languages, the de-facto standard that most developers use is C#, therefore this was the language selected.

* Outline how certain aspects of Unity were utilised during development
* How the code was structured and applied to certain actors within the scene
* How the terrain was created and the issues that arose during trying to get this to work
* The implementation of multiple scenes to create a more complete build of the ‘game’

### Testing

It was vital, upon each implementation of a mechanic or level, to personally test the gameplay impacts of the additions made. As the development of the artefact was carried out in the Unity game engine, which features a quick and simple play-testing mode, it was very straightforward to carry out the testing.

* For testing the game personally, Unity’s inbuilt play mode was primarily used, as this allows for quick and straightforward playtesting on a machine
* Additionally, the logging tools of Unity were used to debug any problems that were occurring and to understand why certain issues were arising
* As the intended platform for the game is a Windows PC, this made building the project very simple as Unity defaults to building for Windows x?? platforms, creating an exe that can simply be run

### Operations and Maintenance

When it came to performing maintenance and operations on the artefact, the relevant sections of the code that were being tested would be altered to output information to *Unity*’s console or, in the event of checking the metrics being tracked for testing purposes, through the external logging text file. This proved to be valuable for working on the terrain deformation implementation, as some issues arose during the development of this mechanic that was difficult to discern from the limited documentation and the deformation appeared to stop working, through this console logging it was discovered that the code was indeed working as intended but the settings of the terrain object itself needed to be changed.

This logging, combined with the straightforward on-the-fly testing through the *Unity* player, allowed for quick maintenance whenever a new feature was implemented and encountered an issue.

## Research

Once the development of the artefact was completed, the next step in the process was to begin the research component and gathering data from play-testers.

The first step here was to try to recruit participants for the study, which required a determination of how many participants would be required and how best to elicit them. As the study would take place on the University of Lincoln campus, participants were recruited from around the University area, through fielding messages on online forums and asking for participants in the computing labs.

As with any study involving human participants, it was vital that ethical procedures were followed…

From here, a study design was laid out in order to structure the process…

# Conclusion

In this section report your findings, answering any research questions posed. This section should be understandable to people who just want to get a general picture of the work and its results.

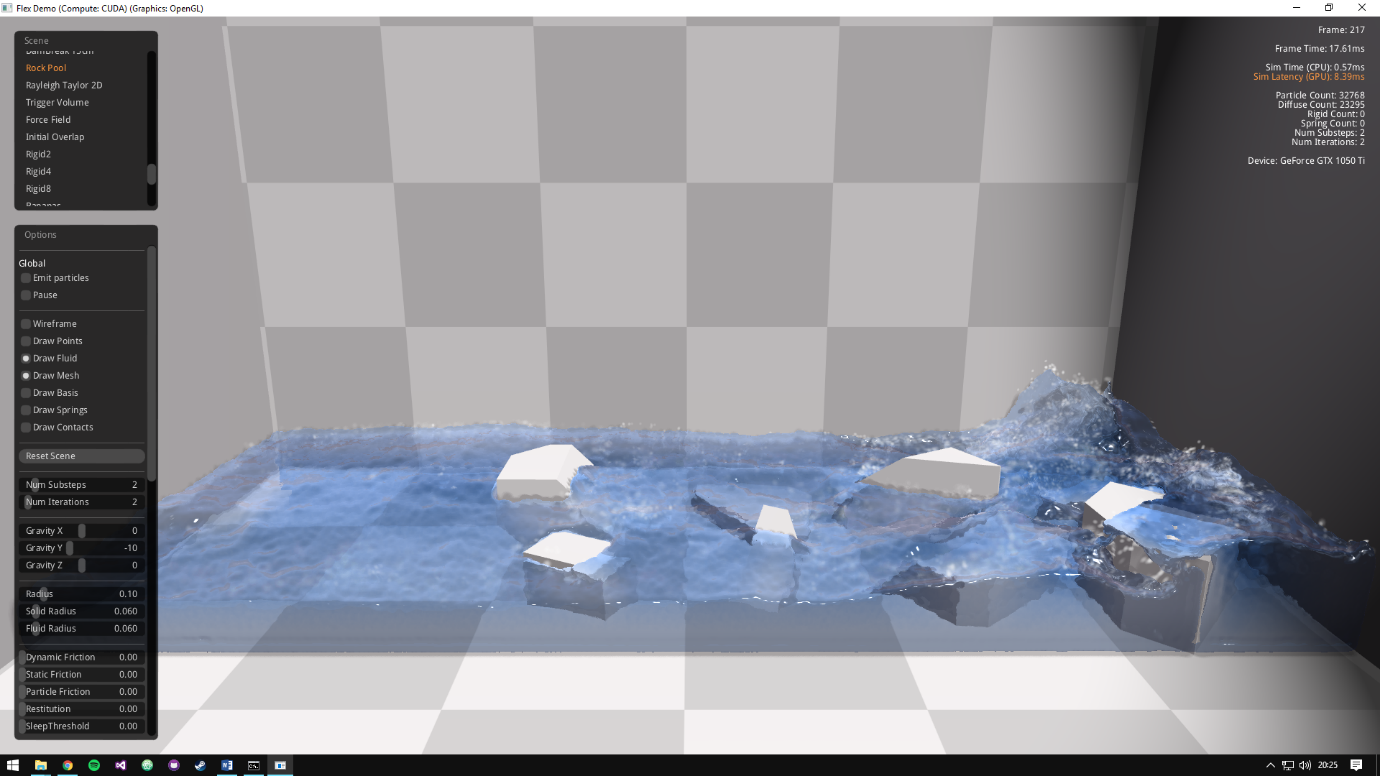
# Reflective Analysis

In general, I found that this project ran relatively smoothly and didn’t encounter any major stumbling blocks, but there are certainly areas where issues arose, and compromises had to be made.

The implementation component of the product overall went rather successfully, as the concept of having player controlled deformable terrain was achieved and this was used to approach puzzle design in an alternative fashion.

With regards to the management of the project, the development of the original Gantt chart in the Project Proposal stage very soon became forgotten in the grand scheme of the project’s undertaking. I feel this is because, while that Gantt chart provided a valuable rough idea of how I would’ve liked the development of the project to pan out, it ended up being unfeasible in the real world. This came as a result of pressures from other assignments and work meaning that, in some instances, more time needed to be devoted to these endeavours which then left the timeframes of that original Gantt chart out of balance. While some amendments were made to the Gantt chart along the way, it soon became clear that having a set time structure for an evolving project such as this would simply not work.

The field of physics simulation in games continues to be an intensely fascinating subject area, as more and more technologies are developed that change the way in which games are applying these physics systems. One example of this is AMD’s TressFX Hair, a real-time physics system used for the simulation of characters’ hair in games, gaining widespread attention in the reboot of *Tomb Raider* (Square Enix, 2013). This library models each strand of hair as an individual element, allowing them all to react individual to forces such as gravity, inertia and wind, allowing the hair to move in a much more realistic way. Competing GPU designer *Nvidia* produced their own implementation of this technology through their *Hairworks* library. The problem with these libraries, as with any physics simulation that introduces a vast amount of additional computations, is that it dramatically impacts performance when they are used in games. However, as technology advances both in terms of CPUs and GPUs, we could see that computational expense either optimised or trivialised.



Another fascinating development in physics simulation technology for games can be seen in *Nvidia’s FleX*, a particle-based technique for real-time visual effects such as fluids, cloth, rope and gases. While it appears like it would be an incredibly intensive system to utilise in games, it already has a competent piece of demo software to show what can be achieved with *FleX*, and has even been implemented in a commercial game, *Killing Floor 2* (Tripwire Interactive, 2016). All these new technologies show promising glimpses of what could be common place in the future of gaming, perhaps even becoming as intrinsic as physics engines have become themselves, hopefully we could even see deformable terrain technology achieve this kind of prominence

The development process of producing the game went successfully but had resulted in some scaled back ambitions from the original ideas I had for the design back at the start of the process. For instance, it was originally planned to have a form of leaderboard system in the game to allow players to compete and see how their friends are doing, which I anticipated using the Google Play services to achieve. However, one immediate issue that sprung up in practice was that the size of the smartwatch made the concept of a leaderboard extremely difficult to implement in a way that the player would easily be able to interpret and interact with. This planned implementation therefore was scrapped in favour of having a personal rewards system for the player in order to encourage them to play the game, which falls in line with many of the academic papers that I investigated over the course of this project. I do however feel that this competitive element could vastly help to encourage engagement with similar games, perhaps those that use the more lucrative size and resources of a smartphone. Therefore, I feel a project that aims to produce a similar type of game but for smartphone platforms could stand to investigate the potential benefits that this feature could have for encouraging prolonged and more intense engagement leading to greater improvements in physical activity.

Another issue that arose was that of asset creation for the game, as this wasn’t an aspect I had considered when beginning work on the game as I wanted to ensure that the code and logic were all in working condition first. However, it became apparent very quickly that to make the product look more professional and have a greater degree of polish, an attractive selection of screens and pictures would need to be produced. Due to my limited experience regarding this kind of asset creation, the final 2D 8-bit style sprites created were not quite of the highest visual fidelity or variation that would be best for a commercial product. Though this may not have been massively important for the scope of this project, I would still consider devoting a bit more time to producing higher quality visual assets for the game in a future project. This is because I feel, from personal experience, having a more visually appealing and professional product may help to encourage people to engage with the game as an attractive façade is likely to encourage greater confidence in the mechanics behind it.

One issue that arose regarding the management of this project was that the earlier tasks outlined in the original Gantt chart turned out to be particularly trivial in relation to other tasks that needed to be completed in the project. This meant that, when trying to follow the original chart at the beginning of the project, the initial tasks were completed very quickly and resulted in a sort-of complacency concerning the state that the project was in, resulting in some lost time that could have been invaluable in later stages of the project’s development. While the Gantt chart was adapted over the course of the project, this constantly changing nature of it became somewhat challenging to keep track of what tasks should be done at what points and when I should stop altering it. In retrospect, I would’ve instead made the original Gantt chart with the anticipation of it being adapted in mind, and factoring that into its setup. However, I feel the inclusion of milestones set throughout the course of the project’s run was incredibly important as it gave a more solid idea of what tangible elements of the project should be together at what points in the timeline. Though, to this, I would in future add milestones for the report’s sections being completed, as this would’ve helped to ensure that the report also had elements completed earlier therefore allowing for further edits and additions.

The shipment data in Figure 7 demonstrates that, while manufacturers such as Garmin saw dramatic relative increases in shipments, the overall number shipped by all noted manufacturers had dropped massively (most notably by market leader Apple’s over 70% decrease in units shipped). This suggests that the public interest in smartwatches has waned incredibly quickly and that, unless a product is introduced in the category to change this perception, this is a market that could struggle to gain any relevant traction. However, as can easily be identified through the limited amount of data provided with this analysis, the market is somewhat in it’s infancy, so perhaps this dramatic change in shipments could be attributed to the fact that it’s a piece of hardware still yet to be proven to consumers.  
Another note to make however, the company Pebble that is included in that information has since been bought out by other wearables company Fitbit. As WIRED noted in their article *Sinking like a Pebble: is the Fitbit buyout a sign the wearables market is doomed?* (WIRED, 2016) devices that run sophisticated operating systems tend, like smartwatches, tend not to be very successful. Of importance in this article is the comment that consumers are shifting away from smartwatches to more simplistic fitness trackers, and that they don’t want gimmicks on their wearables and instead want something that “looks good” and has “the basic features they need”. This means that more complex applications, like the game produced in this project, and the ecosystem around them may not be of relevance as the market moves on. If a game in this manner is to succeed in the current market, it would need to be hardwired into a simpler device that attracts users, instead of the more functional but seemingly overwhelming smartwatch platform.

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# Appendices

## Appendix 1 – Gantt Charts and Tasks



Original Project Gantt Chart



Final Project Gantt Chart

Table of Project Tasks and Milestones Relating to Gantt Charts

|  |  |
| --- | --- |
| Task Number | Task |
| 1 | To investigate the development platforms that are available and determine which would be best for this project, also look into the supporting documentation available for said platform. |
| 2 | Investigate any and all academic literature that holds relevance to what is looking to be done in this project and may help along the way to guide how the project takes shape. This therefore overlaps the entirety of the timeline, as it will be important to try and find relevant academic literature to each task that is being performed. |
| 3 | Experiment with the development platform, get familiar with the coding language used and how to develop basic applications for smartwatches. |
| 4 | Investigate the development APIs available to make use of the sensors available in the smartwatch hardware, as well as ways to store the data retrieved. |
| 5 | Implement the sensor APIs into a basic application along with data storage, configure into a working application. |
| 6 | Draft up designs and paper prototypes for what the game could look and behave like. |
| 7 | Rework drafted designs and ideas into a more polished product. |
| Milestone 1: The prototyping and design phase of developing the project should be complete by this point | |
| 8 | Begin developing this prototype into an application. |
| 9 | Implement the leaderboard functionality into the game. |
| 10 | Personally test out the state of the application & tweak (overlaps with development of the application to portray these ongoing tweaks). |
| Milestone 2: The coding for the game should be complete, ready for testing | |
| 11 | Write up a consent form for the user testing |
| 12 | Carry out user testing. |
| 13 | Compile the results of the user testing and see what conclusions can be drawn from them. |
| 14 | Write up project report. This overlaps the entirety of the project to demonstrate that this will be an ongoing task that will be contributed to at all points in the timeline of the project. |
| Milestone 3: The project should now be fully completed | |
| Slack Weeks: Weeks that are available, should a task take longer than originally anticipated these can then be filled. | |

## Appendix 2 – Game Design Document

**Game Name: Step Quest**  
Theme: Role-Playing Game  
Target Platform: Smartwatch – Android Wear (Sony Smartwatch 3)

Concept:

The player is initially presented with a selection of characters to choose from, whichever character they choose will serve to be their avatar for the duration of their time playing the game.

In traditional role-playing game style the player can earn experience points in order to level up their character and become stronger in order to win more battles. To earn this experience the player needs to engage with the fitness aspect of the game and walk around to raise the pedometer’s step count, this directly feeds into their character’s experience pool.

The primary reason for doing this is to raise their character’s strength for when they encounter a number of random battles that can pop-up as they are walking around. Upon running into one of these random battles, the player is taken to a battle screen where they are presented with themselves, an enemy, both their health bars and an option to attack by tapping on their character’s weapon. Tapping on this weapon will cause the player to attack, causing damage to the enemy’s health by drawing from the player’s strength stat, which they have built up by walking around and levelling up.

The reward the player gets from completing these battles is randomly selected from a number of options, they could:

* Gain a flat bonus to their current experience
* Gain a timed multiplier for their experience gain
* Gain a bonus to their strength
* Gain a bonus to their HP

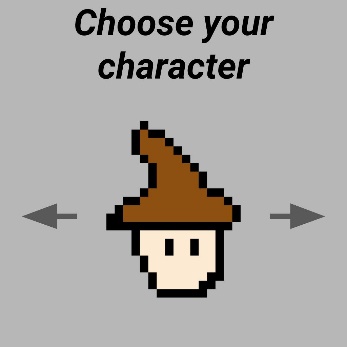
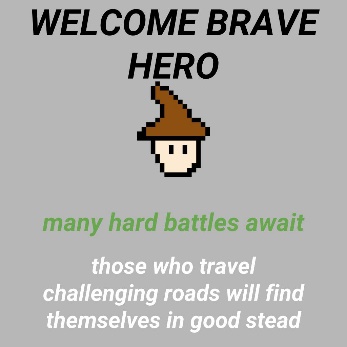
In addition to this, upon completing battle milestones (such as winning 1 battle, winning 10 battles, winning a battle without losing any health etc.) they can also be rewarded with badges. These badges can be accessed from the character screen and can be used to track their achievements throughout their game playing time, and ideally encouraging them to play more to earn further badges.

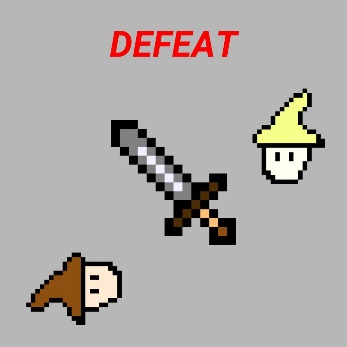
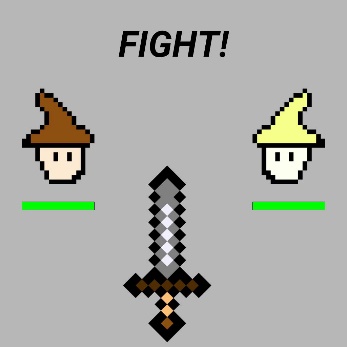
However, should the player lose one of these battles they will be punished for doing so. Again, this will draw randomly from a selection of potential punishments, such as:

* A small subtraction from their current experience
* A decrease in their character’s strength
* A decrease in their character’s HP

The aim is for this to then encourage the player to go out and walk more in order to strengthen up their character before they encounter another battle, thereby decreasing the chances of them being punished for losing again.

## Appendix 3 – Prototyping





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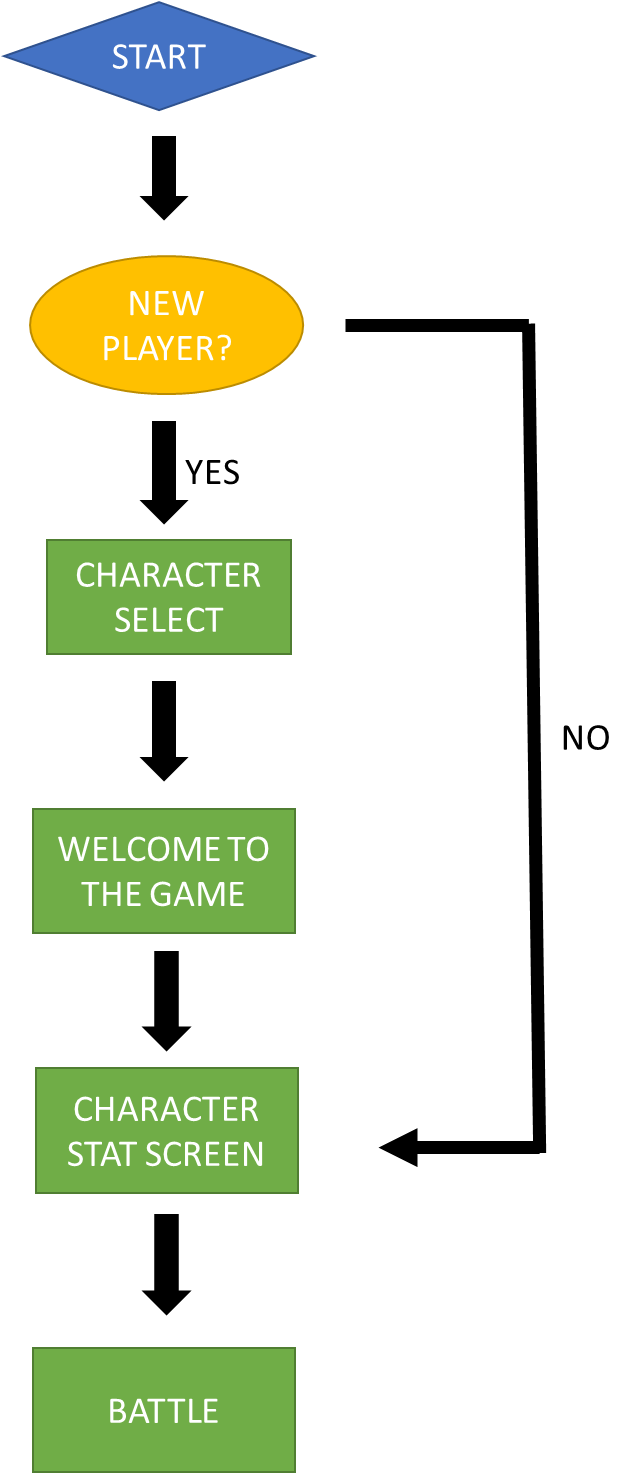
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**1**

Screens:

1. Splash Screen
2. Character Selection Screen
3. Welcome Screen
4. Character Stat Screen
5. Incoming Battle Screen
6. Fight Screen
7. Victory Screen
8. Victory Reward
9. Defeat Screen
10. Defeat Punishment



**Flowchart of how the game should progress through these different screens**

## Appendix 4 – Example User Consent Form

**User Testing Consent Form**

Study Administrator:

Participant:

Participant Number:

This study is focused around the gamification of mobile fitness applications, in particular on the smartwatch hardware platform. The intended audience for this product is tech-savvy young adults who want to engage in more physical fitness but may be in need of encouragement to do so.

For the testing period, you will be provided with a smartwatch with the required applications already installed. For 3 days, we would like you to simply track your steps using a provided step tracker, making note of the total amount of steps you’ve accumulated each day. Then, for the following 3 days, make use of the provided gamified step tracker and again keep note of the total steps taken each day.

The information that will be collected in the testing period will just be what you write in the testing diary supplied to you, which asks you to note down total number of steps you achieve each day and any thoughts you had on the experience.

**Statement of Informed Consent**

Upon signing this document, I indicate that I have read the description of the study and am aware of my rights as a participant. I voluntarily agree to participate in the study.

Print Name:

Signature:

Date:

**[Copies of completed user consent forms available upon request]**