BSc (Hons) Computer Games Development

Serious Games in Chemistry

Computing Honours Project (COMP10034)

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Supervisor: Dr. Mario Soflano
Moderator: Dr. Marco Gilardi

Declaration

This dissertation is submitted in partial fulfillment of the requirements for the degree of Computer Games Development (Honours) in the University of the West of Scotland.

I declare that this dissertation embodies the results of my own work and that it has been composed by myself. Following normal academic conventions, I have made due acknowledgement to the work of others.

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Form to Accompany Dissertation

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I feel that this project as a whole was a great success. It would not have been possible with the help of many individuals guiding and supporting me throughout my dissertation and the development of the game.

Firstly I would like to thank my supervisor Dr. Mario Soflano for being by my side through the whole project, answering my midnight emails, and coming up with many different game ideas which eventually lead to combining most of them together to create the final game.

Secondly I would like to thank Dr. Iain McLellan, the Chemistry lecturer who was interested in my different game ideas, responded to which ones could work and couldn't, and after I landed on my final iteration, helped come up with scientifically-correct interactions and appliances.

I would also like to thank my Chemistry friends - Simon Davit, Kristin Kostadinova, and Mareem Amin for coming up with different ideas along with Dr. Iain McLellan and deciding which ideas would be the most fun for me to implement.

Finally I would also like to thank my friends who unknowingly gave me feedback on how to improve the game, and all the participants of the experiment for taking time out of their busy schedules to play my game.

Project Specification

Project Title:	Serious Games in Chemistry
Student:	Yu-Ching Ho
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Supervisor:	Dr. Mario Soflano
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Outline of Project:
The majority of Serious Games are not engaging like they are compared to major AAA titles like “Grand Theft Auto”, “World of Warcraft”, “Call of Duty”. These games achieve those engagement levels by having a compelling story, and most importantly, gameplay which is “fun”.

A Serious Game is a concept which the player uses a video game to learn a subject. Serious Games intend to blend learning materials into the game directly therefore the player does not feel like they are “learning” but are doing so through repetitive gameplay.

My project will investigate the effectiveness of using a video game to revise the topic of basic Chemistry. The subject area will be based on 1st Year Chemistry learning materials., which involves is the atomic numbers for the first 18 elements of the Periodic Table in Chemistry. Playing the game will refresh the topic which may have been forgotten due to the passage of time, and hopefully captivate the player enough to play more - thus reinforcing the materials learnt through the time spent playing an endless, repetitive game, and constantly improving by beating their own personal high score.

A Passable Project:
- Perform a literature review on video games in general and serious games.
- Integrate the provided learning material into the game.
- Create repetitive endless gameplay.
- Perform surveys on the university’s 1st Year Chemistry students stating whether they preferred playing the game or learning traditionally through blackboard teaching.

A First-Class Project:
- Build guidelines on how to make a Serious Game stand out.
- Deliver on multiple devices and platforms and allow the students to download.
- Perform detailed analysis on the data recorded.

Reading List:

- Cheng, M. (2015). The Use of Serious Games in Science Education: A Review of Selected Empirical Research from 2002 to 2013. Journal of Computers in Education. Vol 2 (3), p. 353-375.
- Merrilea, M. (2007). Games for Science and Engineering Education. Magazine Communications of the ACM. Vol 50 (7), p. 30-35.

- Landers, R. (2015). Developing a Theory of Gamified Learning. Simulation & Gaming. Vol 45 (6), p. 752-768.
- Connolly, T.M., Boyle, E. A., MacArthur, E., Hainey, T., Boyle, J. (2012). A Systematic Literature Review of Empirical Evidence on Computer Games and Serious Games. Computers & Education. Vol 59 (2), p. 661-686.
- Domínguez, A., Saenz-de-Navarrete, J., de-Marcos, L., Fernández-Sanz, L., Pagés, C., Martínez-Herráiz, J. (2012). Gamifying Learning Experiences: Practical Implications and Outcomes. Computers & Education. Vol 63, p. 380-392.
- Hamari, J., Shernoff, D. J., Rowe, E., Coller, B., Asbell-Clarke, J., Edwards, T. (2015). Challenging Games Help Students Learn: An Empirical Study on Engagement, Flow and Immersion in Game-Based Learning. Computers in Human Behaviour. Vol 54, p. 170-179.

Resources Required:

- The material of what the university 1st Year Chemistry students are learning.
- Adobe Photoshop
- Audacity
- Microsoft Word
- Unity 2D
- Unity Asset Store

Marking Scheme:	%
Abstract	5
Introduction	10
Literature Review	15
Requirements and Design	15
Implementation	20
Testing / Evaluation	10
Analysis	10
Conclusion	10
Critical Self-Appraisal	5

Signed:

Student **Supervisor** **Moderator** **Year Leader**

IMPORTANT: ***By signing this form all signatories are confirming that any potential ethical issues have been considered and necessary actions undertaken and that Mark Stansfield (Module Coordinator) and Malcolm Crowe (Chair of School Ethics Committee) have been informed of any potential ethical issues relating to this proposed Hons Project.***

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Abstract

Serious Games is a growing sub-sector of the video games industry, undertaken by many researchers but is still dwarfed by the other other popular game genres focused mainly by many AAA companies.

This paper will research the video games market and the serious games market, build a guideline on how to make a state-of-the-art serious game, and build a video game based off the guidelines. Since serious games can delve into numerous different subjects, the game created will focus the effectiveness of teaching a small sub-topic of foundational Chemistry, address the problems faced and compare the results obtained with past experiments.

1. Introduction

Why do people play video games? Considering the brief lifespan of the birth of the Internet and computers, video games have always been popular. Another niche of the video game market that has been growing is serious games. Serious games' primary target is education - the player learns while playing the game. To achieve such a goal, one of the processes implemented is called gamification.

However not many games are geared towards the secondary education and higher education sectors, therefore one of the major subjects learnt - chemistry - will be explored. The challenges of learning chemistry in general will be looked at, and then a specific subject area will be analysed.

Research of the serious game market will help build guidelines on how to classify a serious game as state-of-the-art. The research can help find some chemistry games that have already been evaluated or used in an experiment, and their results can be compared and contrasted.

2. Literature Review

2.1. Video Games

2.1.1. A Brief History

In February 1946, the first programmable computer was built by the US military to solve large numbers of numerical problems. It was called the Electronic Numeric Integrator and Calculator, or ENIAC. ENIAC was used by Alan Turing to break the Enigma Code used by the Germans in World War II, and one year later, Turing became the first person to write a computer chess program (History of Computing, n.d.).

Later, in 1951, for The Festival of Britain, a British Computer Company - Ferranti - agreed to participate and an engineer called John Bennett developed Nimrod, the first computer to play the game “Nim” against a human opponent. Bennett aimed to show the public the mathematical prowess of a computer, however the public were not interested and wanted to play games instead (Festival of Britain, n.d.).

One of the first video games developed was called “Tennis For Two”, in 1958 for the Brookhaven National Laboratory Open Day by American physicist William Higginbotham and Robert Dvorak, using an oscilloscope and two controllers (The First Video Game, n.d.).

Tennis for Two (1958)

Spacewar! was the next video game to be developed, in 1961 by MIT students Steve Russell, Martin Graetz, and Wayne Wiitanen. The creators were considering on selling the game but as it required a very expensive computer to play it, they gave it away for free (The History of Spacewar, n.d.).

Spacewar! (1961)

Spacewar! inspired several prominent people - Bill Pitts, Hugh Tuck, Nolan Bushnell, and Ted Dabney. Pitts and Tuck wanted to make a sequel to Spacewar! and make a profit, thus a decade later in September 1971, the first coin-operated video game Galaxy Game was released. During this time, Bushnell and Dabney also had the same idea with the differences of they could lower costs dramatically while Pitts and Tuck could not. The other difference was that they were making a different game, and so two months later in November 1971, Computer Space was released (Computer Space, n.d.).

Computer Space became very popular with Stanford University students and the success led to Bushnell and Dabney to create the very first video game company Atari, Inc. On the same day Atari was formed, they hired trainee Al Alcorn. To give Alcorn something to work on that could not harm the company, he was told to work on a ping-pong style game, to which Alcorn worked very hard on. He made the ball bounce at different angles according to where the ball hit the bat, added scores, sound effects, making it fun - leading to the first game Atari published in 1972 called Pong (Pong Game, n.d.).

With the success of Pong, Atari kickstarted the video game industry and went on to release a number of famous games - Breakout in 1976, Space Invaders in 1978, Asteroids in 1979, and Pac-Man in 1980 (The 10 Best Atari Games, 2013).

2.1.2. Characteristics of Video Games

There are many characteristics a video game could include. Examining the comparisons between video games and slot machines, important characteristics they both share were identified (Wood, Griffiths, Chappell and Davies, 2004):

- Response to predictable stimuli.
- Concentration.
- Hand-eye coordination and concentration.
- Rate of play (though negotiable by skill of player).
- Aural and visual rewards for a winning move.
- Incremental rewards due to gameplay.
- Displayed scores which allow digital currency to be gathered.
- Opportunity of peer group attention and competition.

Video games add onto those characteristics (Wood, Griffiths, Chappell and Davies, 2004):

- Sound - realistic use of sound effects, character dialog, background music, narration.
- Graphics - realistic or fitting character movement in relation to art style.
- Background and setting - whether the video game is based on a story, film, or whether the world was made up, each element must stay consistent.
- Duration of the video game.
- Rate of play - how quickly the player is absorbed into the gameplay flow.
- Advancement rate - how the game advances either in gameplay or difficulty.
- Use of humour - either through gameplay, narration, or character dialog.
- Control options - what setting options the player can control.
- Game dynamics - this covers a wide spectrum of many different types of gameplay that can be combined and intertwined such as:
    - Exploring new areas.
    - Elements of surprise.
    - Fulfilling a quest.
    - Skill development.
    - AI interactions.
    - Finding, collecting, or avoiding things.
    - Shooting.
    - Different endings.
    - Different modes of transport.
    - Solving puzzles or time-limited problems.
    - Beating times.
    - Cheats / Easter eggs.
    - Building environments, and mapping.
    - Linear / non-linear game format.

- Winning and losing features.
- Character development.
- Brand assurance - brand loyalty and celebrity endorsement.
- Multiplayer features - playing against other players either online or locally, or playing against AI.

2.1.3. Why Do People Play Games?

As the characteristics of video games have been identified, there are many elements that will keep a player playing and the ones that stand out most are the achievements and rewards, advancement rate, multiplayer features, and rate of play (Wood, Griffiths, Chappell and Davies, 2004).

Receiving achievements and rewards for playing the game incentivize the player to continue on playing, building or collecting all the achievements the game has set out, while being rewarded for good gameplay. This also activates the brain's reward and pleasure centers, releasing the neurotransmitter dopamine, and thus basic body functions tell the player "I feel good while playing this game, so let's keep on playing it" (Psychology Today, n.d.).

The advancement rate and multiplayer features allow players to compete with each other and see their rank according to the rest of the players. Being competitive is a big reason to many male players - often they have the mindset of "I want to be the best" - and a positive feedback loop many games have is reserving the biggest / best / rare rewards to the top players, which then those players can show the other players their status in the game's social hierarchy, gaining respect amongst their peers and fan base.

The rate of play links into a positive psychological state of immersion called the flow state. "Being in flow" is the way some interviewees described the subjective experience of engaging just-manageable challenges by tackling a series of goals, continuously processing feedback about progress, and adjusting action based on this feedback. Under these conditions, experience seamlessly unfolds from moment to moment, and one enters a subjective state with the following characteristics (Csikszentmihalyi, Abuhamdeh and Nakamura, 2014):

- Intense and focused concentration on what one is doing in the present moment.
- Merging of action and awareness.
- Lost of reflective self-consciousness.
- A sense of being in control and being able to respond to whatever happens next.
- Distortion of temporal experience (typically a sense that time has passed faster than normal).
- Doing the act of the activity is intrinsically rewarding.

All of the above characteristics help identify if a process has gone under the process of gamification. Gamification is the process of taking something that already exists and integrating game mechanics into it to motivate engagement, participation, and loyalty (What is Gamification, n.d.).

2.1.4. Video Game Genres

Different playstyles and each major genre can be blended with one-another to create new genres or subgenres, all with different perspectives examples being 2D, 3D, first person, isometric view, top-down, or side view (Various Video Game Views, n.d.).

There are eight major genres (Adams, 2013):

1) Action
2) Adventure
3) Role-Playing (RPG)
4) Simulation
5) Strategy
6) Sports
7) Idle
8) Purpose

Action

Action games require good hand-eye coordination and motor skills to overcome the challenges presented, as the gameplay centers around the player for example the subgenre shooting games. There are many other subgenres such as platform games like Super Mario Bros, fighting games, beat 'em up, stealth, survival, and rhythm games.

Adventure

Adventure games follow a storyline in which the story can develop in many ways depending on what choices the player makes or puzzles solved. They can take the form of just pure text adventures - an interactive story, graphical adventures - a more developed form of text adventures where instead of typing in the command, the player clicks an icon instead. Finally, there are visual novels, where the game feature static graphics and the player can have a various number of story endings with the options chosen.

Action-Adventure

Some genres melded together to create a noticeable genre "action-adventure". This genres takes main components from both genres and combines them, to create the subgenres survival horror and metroidvania. Survival horror is as the name suggests, games focusing on fear and trying to achieve this through their environment and atmosphere, unknown monsters, immersiveness especially with virtual reality but more prominently through first-person view.

Metroidvania games allow players to explore a large closed-world map, but due to their current skill-level in the game, cannot explore each section fully. As the player levels up progressing through the game, the player can then backtrack to previously locked sections and unlock them due to being the appropriate level to do so.

Role-Playing (RPG)

Role-playing games are similar to adventure games with the following of a storyline, however instead of the player looking in from an outsider's perspective, the player becomes the character, with often games allowing customisation and specialising in different skill sets (e.g. melee tank, ranged caster, etc). Action role-playing incorporate a lot of combat, relying on hand-eye coordination, motor skills, and reaction time.

There is also a subgenre called "First-Person Party-Based RPG" and these type of games consist of the player leading a number of characters, controlling their actions separately but still as one party, proceeding through a set storyline in within the world. Many are turn-based, though some are played in real-time. Leading off first-person party-based RPGs, there is one which does not have a party and more often in 2D called roguelikes, and then there are tactical RPGs where the player controls a party which cannot exceed a certain number, and battles against similar enemies in turn-based tactical movement gameplay.

Sandbox RPGs allow the player to do whatever they want while following a loose storyline, and without any set goals or checkpoints to reach. They are very interactive and great example games would be from the Grand Theft Auto franchise. A similar subgenre to this is the MMORPG, or the massively multiplayer online RPG. They allow the players to explore a huge world online, with each player on different paths and quests, but allowing players to band together and complete missions usually not possible by one-self. World of Warcraft defined the subgenre of MMORPG and even years after its release in 2004, remains one of the most popular game in its subgenre.

Simulation

Simulation games cover a wide number of genres, but their main purpose is to copy real life as accurately as possible. An example of this is vehicle simulation like the Truck Simulator franchise where the player drives a truck through the world and everything is as accurate as possible - the size, scale, and weight of the truck, and the world, roads, and traffic.

Vehicle simulation can also include military usage as combat pilot simulators are used to train pilots to react to situations that could possibly be encountered, while not putting any property or the pilot in any actual danger or damage. There are construction and management simulation games where the player manages a city or business, and life simulation games, where the player plays as a god and oversees the rise of a virtual empire.

Strategy

The many strategy subgenres are very similar to one another aside from a few. Multiplayer online battle arena, or MOBA, consist of having one team of a set party size against either AI or another team the same size, and each player controls one character who has a set number of abilities, and the teams will work together to win the game.

Tower defense games are where the player places turrets strategically to defend against waves of enemies, progressively getting stronger over the course of the game. Artillery games consist of players controlling one character or a small team and having limited or no

movement, while attempting to destroy the other player under a time-limit. A great example would be the Pocket Tanks game or the Worms franchise.

Then there are war games usually under the 4X category, with the four primary goals of eXplore, eXpand, eXploit, and eXterminate. These games can be split up into four sections - real-time strategy, real-time tactics, turn-based strategy, or turn-based tactics.

Real-time strategy has the player being able to control the expansion and growth of a civilization and its army, defending against at least one opponent, with the expansion and combat in real-time. Real-time tactics is very similar, though the control of the army through a general: therefore the commands are not instantaneous as the troops may already be in contact and cannot disengage immediately or under an emotional effect which do not allow them to react. Turn-based strategy and turn-based tactics are similar to their counterparts, with the difference being players take turns in a set order and after one completes all the commands desired in their turn, the next player in line takes their turn.

Sports

Sports games simulate sports. Notable subgenres are racing games, sports-based fighting games, or games which manage the sport such as the FIFA franchise.

Idle

Idles games are the player is presented with few trivial tasks, usually one, and is rewarded through completing said trivial tasks. The most famous example is Cookie Clicker.

Purpose

Some video games are designed with a purpose in mind, whether it be an art game, a casual game, a game specifically for a person or event, or a serious game.

2.2. Serious Games

2.2.1. What Classifies as a Serious Game

Early research into video games generated negative publicity about video games, such as playing violent video games can lead to traits leading to violent behaviour. As the research focused on the negative effects, conversely there was interest in the positive effects with the focusing on designing games for educational purposes, and research shows that learning is most effective when it is active, experiential, situated, problem-based and proves immediate feedback with one instance being game-based learning. Modern theories of effective learning suggest that learning is most effective when it is active, experiential, situated, problem-based and problem-based and provides immediate feedback (Connolly, Boyle, MacArthur, Hainey and Boyle, 2012).

In considering what classifies as a serious game, it is useful to consider the primary function of the game - whether it be for entertainment or learning (Connolly, Boyle, MacArthur, Hainey and Boyle, 2012). One can look at the genre of the game but as video games are so dynamic, many genres can overlap and blend together. Therefore the function of serious games, gamification, and game-based learning are distinct from entertainment-oriented games and in that while they are often enjoyable, they are designed for primary end purposes other than entertainment and leisure (Humari, Shernoff, Rowe, Coller, Asbell-Clarke and Edwards, 2015).

2.2.2. Market Research on Serious Games

Studies have unveiled many potential advantages of video games in education, like immediate feedback, information on demand, productive learning, motivation cycles of expertise, self-regulated learning or team collaboration (Domínguez, Saenz-de-Navarrete, de-Marcos, Fernández-Sanz, Pagés and Martínez-Herráiz, 2012), and so serious games have achieved a broader definition now as the number of studies that employ commercial games to facilitate the occurrence of learning has increased (Cheng, 2015).

Currently video games are the most powerful entertainment industry in economic terms, and researchers look to export the good aspects of video games to non-gaming educative contexts by the process of gamification (Cheng, 2015). The principles of science and engineering can be taught not only by playing games but by designing them. Games looked at were “Brianno Coller’s race car game / numerical methods course” - where the students had to apply their numerical methods knowledge to program virtual cars to navigate its race track, a diabetes-management game for children “Packy and Marlon” - reduced urgent-care follow-up visits by 77%, and a game called “Squire’s Quest!” intended to help teach healthy eating strategies to children - increased fruit and vegetable consumption by 30% (Merrilea, 2007).

Any logical task can be gamified (Landers, 2015). A gamification system was proposed that increases student motivation focused on the three fundamental elements that make video games appealing to their players (Domínguez, Saenz-de-Navarrete, de-Marcos, Fernández-Sanz, Pagés and Martínez-Herráiz, 2012):

1) The Cognitive Area.
2) The Emotional Area.
3) The Social Area.

The Cognitive Area

The cognitive aspect are the rules of gameplay, with the game providing a complex system of rules along with a series of challenges and quests, in which the player is guided through each milestone in difficulty through a try and fail cycle until the necessary skill level is acquired. This process is called the "cycle of expertise". The game gives constant encouragement to players, reassuring them that they have the skill and knowledge to break through the next milestone; and each player's progression is unique as the learning process is usually non-linear and depends on what tasks the player accomplishes depending on skill and personal preference.

The Emotional Area

The emotional aspect works around the concept of success and failure. Succeeding gives players immediate recognition and rewards include ingame currency, points, trophies or items on task completion. Failure is carefully managed as games do not want failure to turn into frustration. They do so by having low penalties and tasks designed to fit the player's skill level, to promote experimentation and task repetition. If the difficulty of tasks is correctly balanced, it can drive players to a highly motivating positive psychological state of immersion called flow.

The Social Area

The social aspect usually involves multiplayer and allowing players to interact with one another, whether to converse or complete challenges not usually possible as a solo player. Another mechanism even for single-player games would be leaderboards and seeing how their play competes regionally and globally. The cognitive area and emotional area also feeds into the social area, as rewards / trophies / tokens can be limited to certain players who have been playing from the very start, or who have achieved the highest level of difficulty / rank, and so the rewards can elevate the player to a certain status among the game's player base and receive positive social feedback among their peers.

The gamification system was injected into an e-learning platform for the course "Qualification for users of ICT" where students of different grades learn how to effectively use common ICT tools, and studies showed that while it did increase student motivation, there were positive and negative side effects (Domínguez, Saenz-de-Navarrete, de-Marcos, Fernández-Sanz, Pagés and Martínez-Herráiz, 2012).

The positive effects reported by students were:

- “I can know what is the amount of work that I have done with respect to other students”.
- “Because the leaderboard was motivating for me”,
- “Submitted to the new virtual platform to win new points as it is fun and motivating in many ways, be it for the graphics, the trophies… and it is even more colourful and encouraging”.

The negative effects reported by students were:

- “Too many students”.
- “I do not like competition between students and that everyone can see it”.
- “I don’t think that leaderboards are a good representation of who gets more knowledge about the course”.
- “It would be more interested to improve the traditional version, instead of making competitions”.
- Students preferring traditional-like activities because “they are easier”, or “feel more comfortable”.
- Students feel manipulated by participating in extrinsic motivation - the motivation to perform an activity to earn a reward or avoid punishment.

Within the gamification system, nine categories were identified as attributes (Landers, 2015):

1) Action Language - the method and interface a player communicates with a game, whether on a specific device or platform or controller.
2) Assessment - how accomplishment and game progress are logged.
3) Conflict / Challenge - the nature and difficulty of problems presented to players.
4) Control - how much players can alter the game, and how the game responds.
5) Environment - the virtual surroundings to the player character.
6) Game fiction - the fictional game world and stories.
7) Human Interaction - how players can communicate and interact with each other.
8) Rules / Goals - the rules, goals, and information on the progress towards those goals.
9) Immersion - the affective and perceptual experience of a game.

There is an obvious way to achieve immersion through the devices used and that is through virtual reality. However there is a highly motivating positive psychological state of immersion called flow, which can be achieved in games regardless of perspective due to the game’s rate of play. As players are playing a game, they have to abide by the game’s rules and regardless of their progression in the game, players will be learning new ways to play the game whether it would be new items, or areas of the game unlocked due to the current difficulty.

This challenge-skill dynamic introduced a growth principle which is also inherently related to learning. When learning a new skill, the challenge of even a basic task may exceed a player’s beginning level of ability, and hence one may feel overwhelmed. To reach flow, the level of skill must increase to match the challenge. A higher level of challenge is then issued after that milestone is achieved, and the player once again must go through the cycle of expertise to complete the challenge. Because games can uniquely adjust and push the

players not to give up, the continuous cycle of expertise becomes so enjoyable that players are intrinsically motivated to improve their skills and re-enter the state of flow. The level of difficulty cannot feel too easy or too difficult, otherwise instead of enjoyment there would be frustration. Enjoyment can be produced when the three components - competence, accomplishment, and performance - are all equally simultaneously stimulated, and the engagement in learning is at its highest when achieved (Hamari, Shernoff, Rowe, Coller, Asbell-Clarke and Edwards, 2015).

The sense of immersion has shown in neuroscience that the human brain is activated in areas responsible for attention, affect, and emotion, and having students do homework in a game-based learning learning environment was able to both support learning and promote engagement. Gamification settings and voiceovers influence engagement and the state of flow, and while they did have a positive effect on student performance in the game, they did not have an effect on learning outcomes (Hamari, Shernoff, Rowe, Coller, Asbell-Clarke and Edwards, 2015).

2.2.3. A State-of-the-Art Serious Game

A guideline on how to make a Serious Game stand out was constructed from the prior research and literature review. The four tips helps consider each aspect when building a such a game.

1) What are the Learning Objectives?
Think about what is the game is trying to teach, and what the learning outcomes a player should have playing through / completing the game.

2) What is the Genre?
Decide what kind of genre will best fit the gameplay to achieve the created learning objectives. Adventure or role-playing games constitute the most popular genres among serious games as they allow the students to construct identities in virtual worlds by customising their own avatars. Those avatars then allow the students to interact with authentic learning environments (Cheng, 2015).

3) Utilise the Gamification System
Look at the the three fundamental elements that make video games appealing to their players, and generalise what is required in each area (Domínguez, Saenz-de-Navarrete, de-Marcos, Fernández-Sanz, Pagés and Martínez-Herráiz, 2012):

3.1) The Cognitive Area - Summarised as gameplay and rules.

3.2) The Emotional Area - Summarised as success and failure.

3.3) The Social Area - Summarised as interaction and recognition.

4) Specify the 9 Attributes

Then construct the game around the general gamification system and specify what is needed in the nine attribute categories. All these attributes are present in serious games but vary in degree, while gamified learning, specific game attributes are targeted, extracted, and adapted to non-game contexts (Landers, 2015).

4.1) Action Language

How the student will play the game and what device they play on will allow the gameplay and controls to vary.

4.2) Assessment

How will progress be tracked? One of the most explored gamification concepts outside of learning is the use of leaderboards that track and display the current performance level of various players to all other players.

4.3) Challenge

Look at the learning objectives and decide how they will be presented within the game world.

4.4) Control

There should be a degree of fluidity within the game, whether it would be an open world format, or different storyline options and answers.

4.5) Environment

The virtual environment, as good practice, should be as congruent to real-life as possible. This can also be built on by allowing students to interact with things not normally possible - for example handling each periodic table element and seeing their physical composition.

4.6) Game Fiction

How the learning objectives are presented in the game world. Lectures, tests, and discussions can be renamed to adventures, monsters, and councils respectively.

4.7) Human Interaction

Decide whether the game will be single player or multiplayer. How can the player gain social recognition, and if it is only multiplayer, allowing certain challenges only be solved in a group can increase human interaction.

4.8) Rules / Goals

See the learning objectives and how they will define the gameplay rules and goals.

4.9) Immersion

Consider the perspective of the game - 2D, 3D, Virtual Reality, and consider how to achieve flow within the cycles of expertise, as both the conditions for flow - challenge and skill, coupled with engagement had a positive association with learning (Hamari, Shernoff, Rowe, Coller, Asbell-Clarke and Edwards, 2015).

2.3. Chemistry in Serious Games

2.3.1. Challenges of Learning Chemistry

One of the many challenges of learning Chemistry can be the lack of student motivation due to the limited capacity of interaction with the teacher and classmates (Domínguez, Saenz-de-Navarrete, de-Marcos, Fernández-Sanz, Pagés and Martínez-Herráiz, 2012), or the pervasive student disengagement resulting in having low participation and or a low sense of belonging (Hamari, Shernoff, Rowe, Coller, Asbell-Clarke and Edwards, 2015), or a failure in proper science education, with only a small portion of students being prepared for college science (Merrilea, 2007). Attention spans are also decreasing with the rise of technology - phones, games, social media, all which partake in giving instant gratification.

In addition to the above, scientific concepts are increasingly more hypothetical and complicated than other subjects and scientific inquiry and problem-solving skills often require long-term cultivation and repeated practice. Students have to take the concepts already learnt and then apply them to problems in a variety of situations and unfamiliar contexts. The traditional views on science education mainly focus on fact memorization do not really fit the needs of today's learners and serious games along with gamification can be an effective and powerful tool for science learning because of their unique capacity for combining serious subject matter with enjoyment (Cheng, 2015).

The increased engagement via serious video games and gamification has resulted in students having higher motivation, which in turn, increases self-efficacy, self-worth, and competence (Hamari, Shernoff, Rowe, Coller, Asbell-Clarke and Edwards, 2015), and serious games have a lot of potential due to their massive reach worldwide, effective learning paradigms, enhanced brain chemistry, the time spent playing, and their learning outcomes data (Merrilea, 2007).

2.3.2. The Chemistry Topic

The specific subject area that will be focused on is the knowledge of the first 18 elements of the Periodic Table. This subject area was chosen to give students the opportunity to learn or practice and build a strong foundation in their chemistry knowledge.

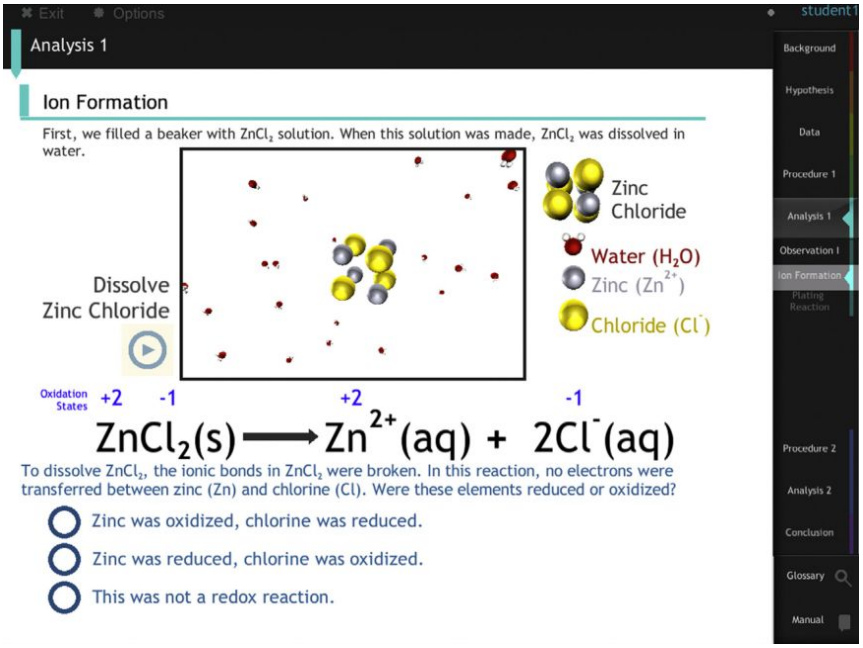
The knowledge around the first 18 elements will be knowing the atomic number and what group they are in. This is important as balancing chemical equations, knowing moles and molarity, titration calculations, and balancing equations for redox reactions all require that prerequisite knowledge.

Learning this subject area is not hard, but being able to keep that knowledge in the long term memory and being able to immediately recite it without having to go back and check will save a lot of time and effort.

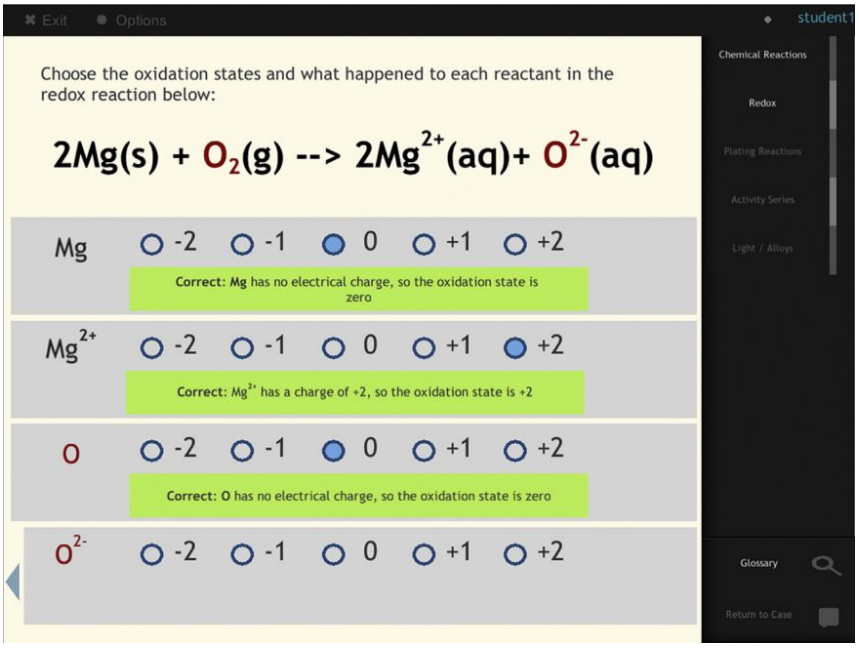
2.3.3. Market Research on Chemistry Serious Games

An Exploratory Study of Blending the Virtual World and the Laboratory Experience in Secondary Chemistry Classrooms

Hodes, Wang, Lee, Cohen and Jang (2017) created a game to help support the learning of microscopic phenomena by making the invisible visible. Microscopic / molecular level concepts such as the mole, chemical bonding and chemical equilibria are hard for high school students to visualize and conceptualize, therefore a way to bring them into the "real world" was to create a virtual chemistry lab to interact with those concepts.



Screenshot of Picture 2. Embedding assessment in the BRE.

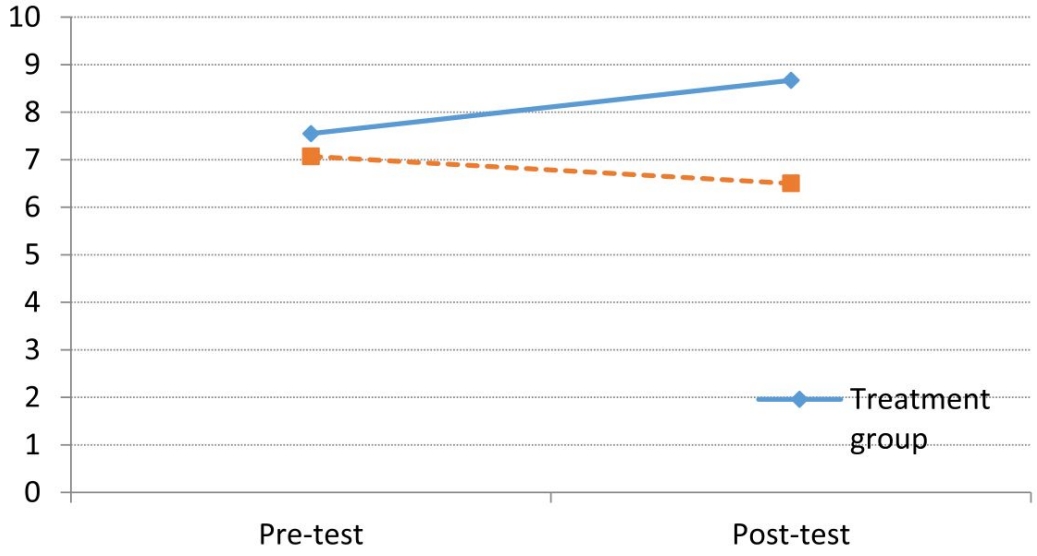


Screenshot of Picture 3. Providing elaborate feedback in the BRE.

The students were split into two groups - the treatment group (BRE), and the control group (BAU). Graphs below show the results of a Pre-Test and Post-Test questionnaire:

Table 1
Descriptive statistics of total scores.

Group	Test	N	Mean	SD
BRE	Pre-test	184	7.55	2.79
	Post-test		8.67	3.18
BAU	Pre-test	167	7.07	2.45
	Post-test		6.50	2.18

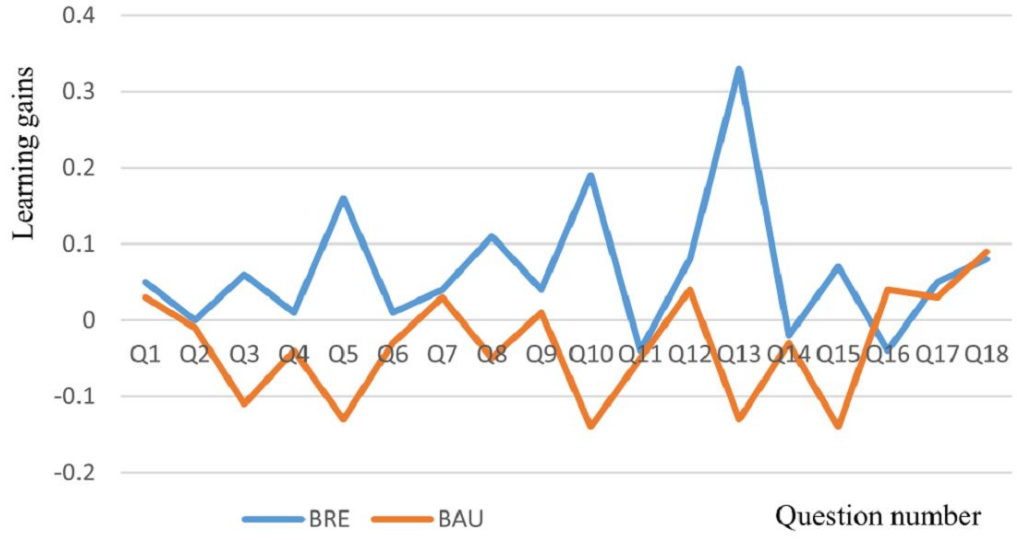


Screenshot of Fig. 2. Means of the total scores for the Pre-Test and Post-Test by group.

Table 2
Descriptive statistics of gain scores by gender and group.

Independent variable		N	Mean	SD	*F*	Effect size (η^2)
Treatment	BRE	179	1.12	2.85	32.44*	.09
	BAU	164	−0.56	2.44		
Gender	Male	156	0.32	2.84	0.01	.00
	Female	177	0.34	2.75		

Note. *p < .05.



Screenshot of Fig. 3: Learning gains of the BRE and BAU groups of individual questions.

The screenshots show that the treatment group (BRE) scored higher than the control group (BAU) in the Post-Test; the learning gains of individual questions show that where most BRE students score higher in, BAU students score lower in.

Using Android-Based Educational Game for Learning Colloid Material

Sari, Anjani, Farida and Ramdhani (2017) created a game to help support the learning of colloid materials. Colloidal materials are used to incorporate additional properties to a solution. A colloid can be defined as a microscopic substance that is suspended in another medium usually a liquid. Colloidal materials can remain evenly distributed in the solution without settling to the bottom or becoming dissolved (Colloidal Materials, n.d.).

As students were expected to memorise colloidal materials, an interactive game was made with 12 different levels to guide students from the basics of colloids to the Tyndall Effect and more. Instructional and educational information were provided in prior scenes, each figure represents a level in the game, and after completing each level, the student is given a video that contains an explanation of the game played (Sari, Anjani, Farida and Ramdhani, 2017).

Figure 1. Visualization of main scene

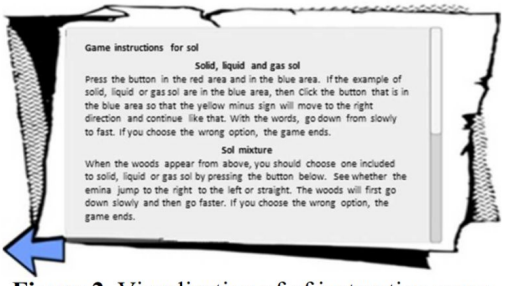


Figure 2. Visualization of of instruction scene

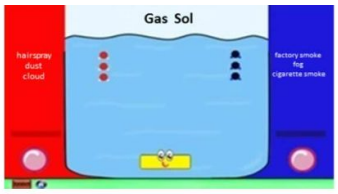


Figure 7. Visualization of Level 3 Scene

Figure 8. Visualization of Level 4 Scene

Figure 9. Visualization of Level 5 Scene

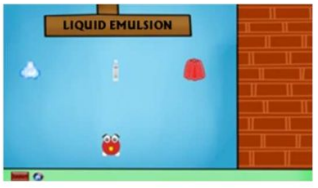


Figure 10. Visualization of Level 6 Scene

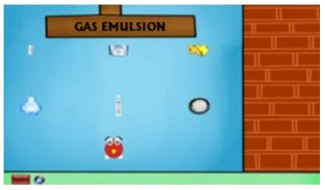


Figure 11. Visualization of Level 7 Scene

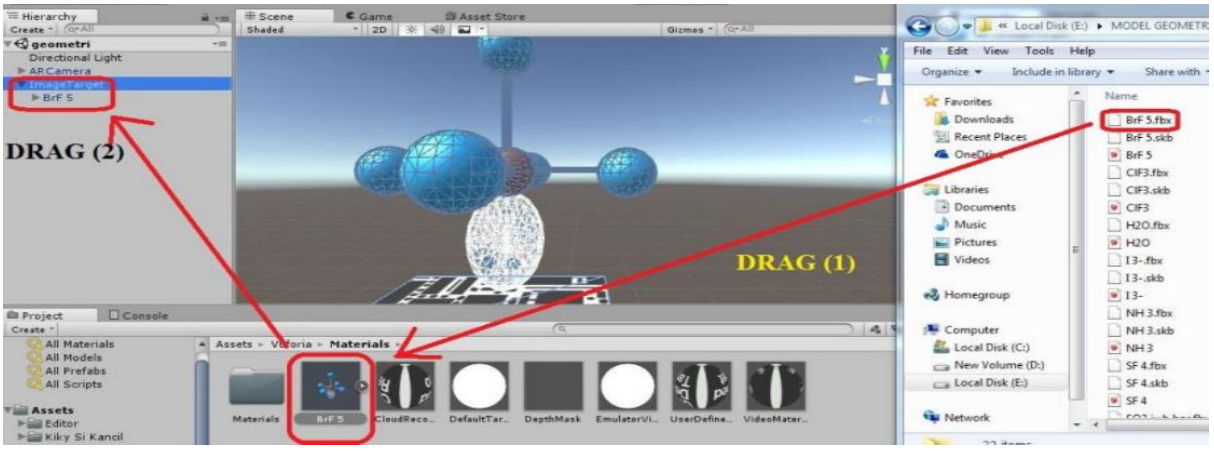
Figure 12. Visualization of Level 8 Scene

Screenshots of Figures

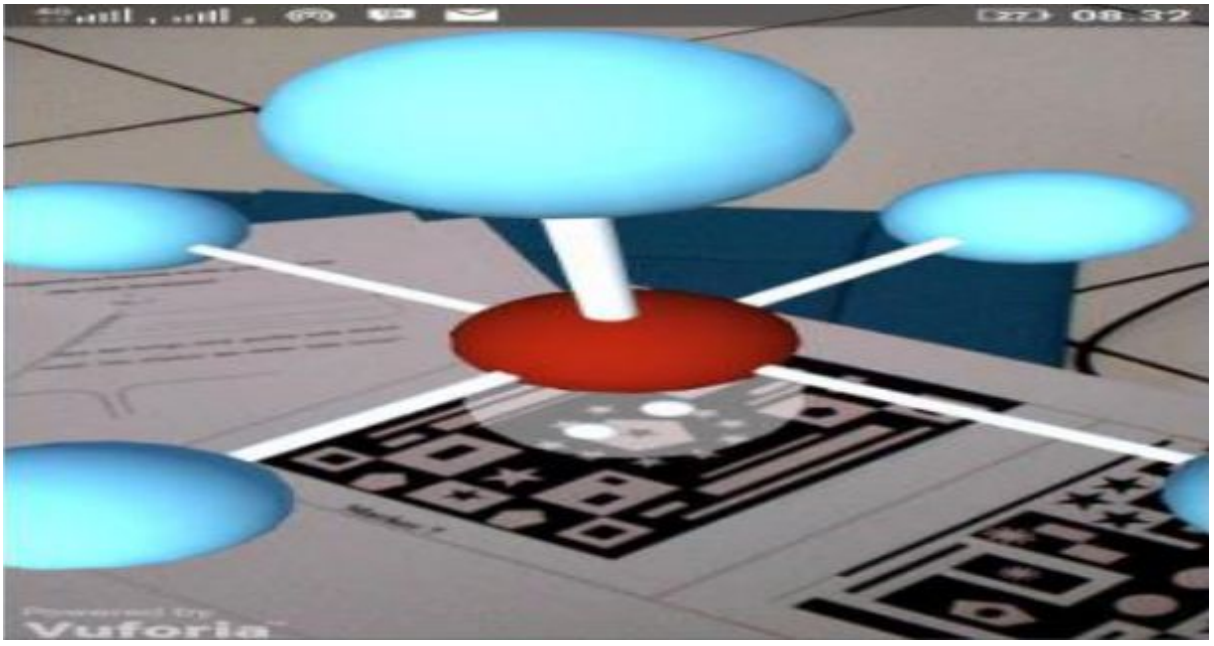
The game was declared as a valid learning media as the results of the questionnaire can be seen on several aspects. The highest r-value was 0.93, the lowest r-value was 0.60, with the average r-value 0.77 for whole aspects assessed (Sari, Anjani, Farida and Ramdhani, 2017).

Augmented Reality Technology on the Android Operating System in Chemistry Learning

Irwansyah, Yusuf, Farida and Ramdhani (2018) created a game to help support the learning of the molecular model and geometry.This was to enhance learning the abstract concepts presented through text and literature and provide intractability to solidify the learning experience.



Screenshot of Figure 5. Combining 3D objects into Unity3D application



Screenshot of Figure 7. AR Learning Media on Android

10 students were randomly selected to install the developed application on their smartphones, and then the students completed a worksheet assisted by the use of the AR application. After the experimentation, students were given a questionnaire to assess the instructional media (Irwansyah, Yusuf, Farida and Ramdhani, 2018).

Indicators	Scores	Criterion	Percentage (%)
Learning Objective Relevance	107	120	89.16
Product Efficiency based on Time	57	80	71.25
Effectivity in Overcoming Media Limitations	91	120	75.83
Media Implementation Flexibility	64	80	80.00
Media Interface	90	120	75.00
Increasing Students' Learning Motivation	87	120	72.50
Learning Support capacity	85	120	70.83
Similar Media Development Prospect	37	40	92.50

Screenshot of Table 1. Questionnaire Results based on Indicators

The percentage range 70.83 - 92.50% indicates the game is qualified enough to be declared as a valid learning media.

3. Methodology

3.1. Research Question and Hypothesis

Based on the literature review researched to create a guideline of how to make a Serious Game stand out, there are four main objectives with sub-objectives:
1) What are the Learning Objectives?

2) What is the Genre?

3) Utilise the Gamification System
3.1) The Cognitive Area
3.2) The Emotional Area
3.3) The Social Area

4) Specify the 9 Attributes
4.1) Action Language
4.2) Assessment
4.3) Challenge
4.4) Control
4.5) Environment
4.6) Game Fiction
4.7) Human Interaction
4.8) Rules / Goals
4.9) Immersion

The game will be more focused on “fun” than “education”. Based on prior research and literature review, once players achieve the flow state, players are more incentivised to come back and play the game again. Serious games focused on “education first” often break the flow state by having players read large quantities of text before allowing them to move onto the next objective - which is often more reading.

The game will be more focused on “fun” through engaging gameplay and spawning friendly units. The units will be described as to what they do scientifically, and through replayability, will slowly remember what each unit does and build different gameplay strategies.

The research question of this project will investigate the effectiveness of games in teaching Chemistry topics, this particular topic being outlined by the learning objectives which will be answered in Section 4. The hypothesis will be:

H_0: The student’s score will not change after playing the video game.
H_1: The student will score higher in revising the basic topic after playing the video game.

3.2. Evaluation Methodology

3.2.1. Types of Research

The main research analysed will either be qualitative or quantitative research. Qualitative research is gathering descriptive data through exploratory research such as observation or case studies. It is used to gain an understanding of underlying reasons, opinions, or motivations of a particular person or within a certain range of demography.

Quantitative research is gathering numerical data through either discrete variables or continuous variables. Discrete variables is data which can be counted. Continuous variables is data which can be measured. The numerical data can be charted, graphed, or presented in a tabular format.

3.2.2. Types of Sources

Qualitative or quantitative research can come from two sources. A primary source is the original source, the person that experienced it first. The participants are undertaking new research which will present new results.

Secondary sources quote the primary source, and add a layer of analysis or interpretation of data on top of the original data. Examples include diaries, newspapers, letters, photographs, recorded interviews, and many more.

3.2.3. Types of Methodology

The methodology is how data is collected and what is used in collecting the data. There are many different types of methodologies, which any number can be used together. Data can be collected by:

- Experiments
- Quasi-Experiments - when the researcher is interested in independent variables which cannot be controlled, such as personality or height of the participant.
- Surveys / Tests / Questionnaires
- Case Studies / Observational Research / Interviews
- Longitudinal Research - repeated observations on a set of variables over an amount of time.
- Cross-Sectional Research - observations on a set of variables at a specific point in time.
- Archival Research
- Ethnography Research - the study of people and cultures.
- Meta-Analysis Research - an analysis that combines the results of multiple studies.
- Content-Analysis Research - an analysis of content in various different formats.

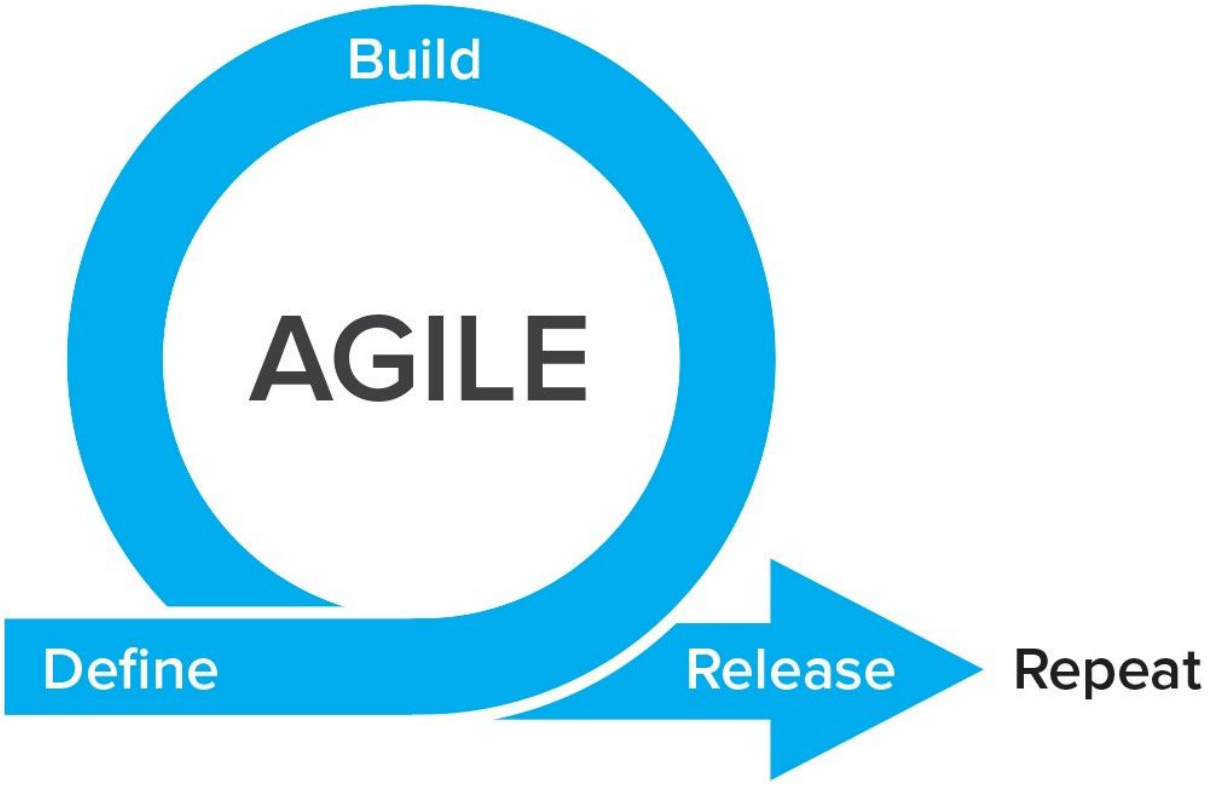
3.2.4. Research Design

The research design is how researchers obtained data and what types of methodology was used to do so. The research can then be characterised as empirical or discussional. An empirical paper has evidence obtained through scientifical or observational study, whereas discussional papers are to find and theorize underlying reasons or opinions presented.

3.3. Software Methodology

3.3.1. Agile Development

The Agile development methodology can most simply be described as “Design, Implement, Test, Release” displayed in the infographic below:



Agile Development: A Quick Overview (2017)

The infographic shows a life-cycle of the development process and each life-cycle is focused on iterative and incremental process, relying on customer or client feedback to adapt and deliver working product features (Agile Development: A Quick Overview, 2017).

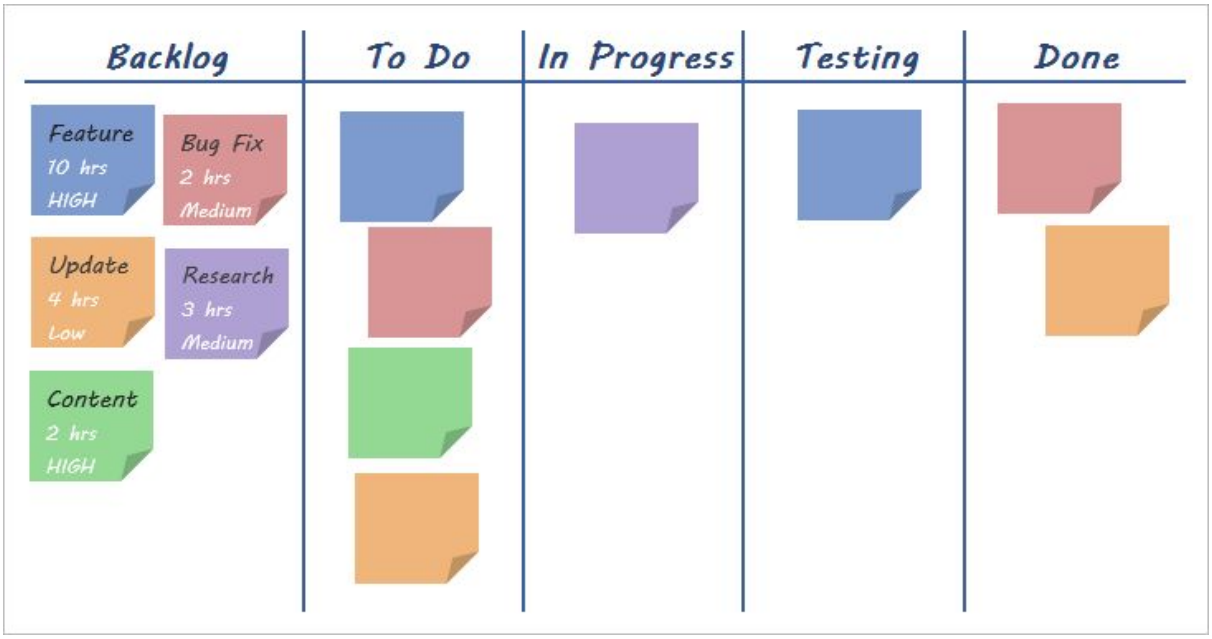
The four main features of Agile software development is (Agile Development: A Quick Overview, 2017):

1) The team and their interactions
2) Product Releases
3) Customer Collaboration
4) Responding to Changes

There are many different types of Agile methodologies to manage workflow, and the two most popular ones will be explained - Kanban and Scrum.

Kanban Workflow

Kanban breaks down tasks into a Kanban Board. In a team using Kanban, there are no set roles prescribed and no time limit for each product feature life-cycle. Continual adaptable improvement is expected from customer or client feedback. Each product feature is moved to their appropriate state and remains until completed and or requires review (3 Differences between Scrum and Kanban, 2015).



Kanban Board (n.d.)

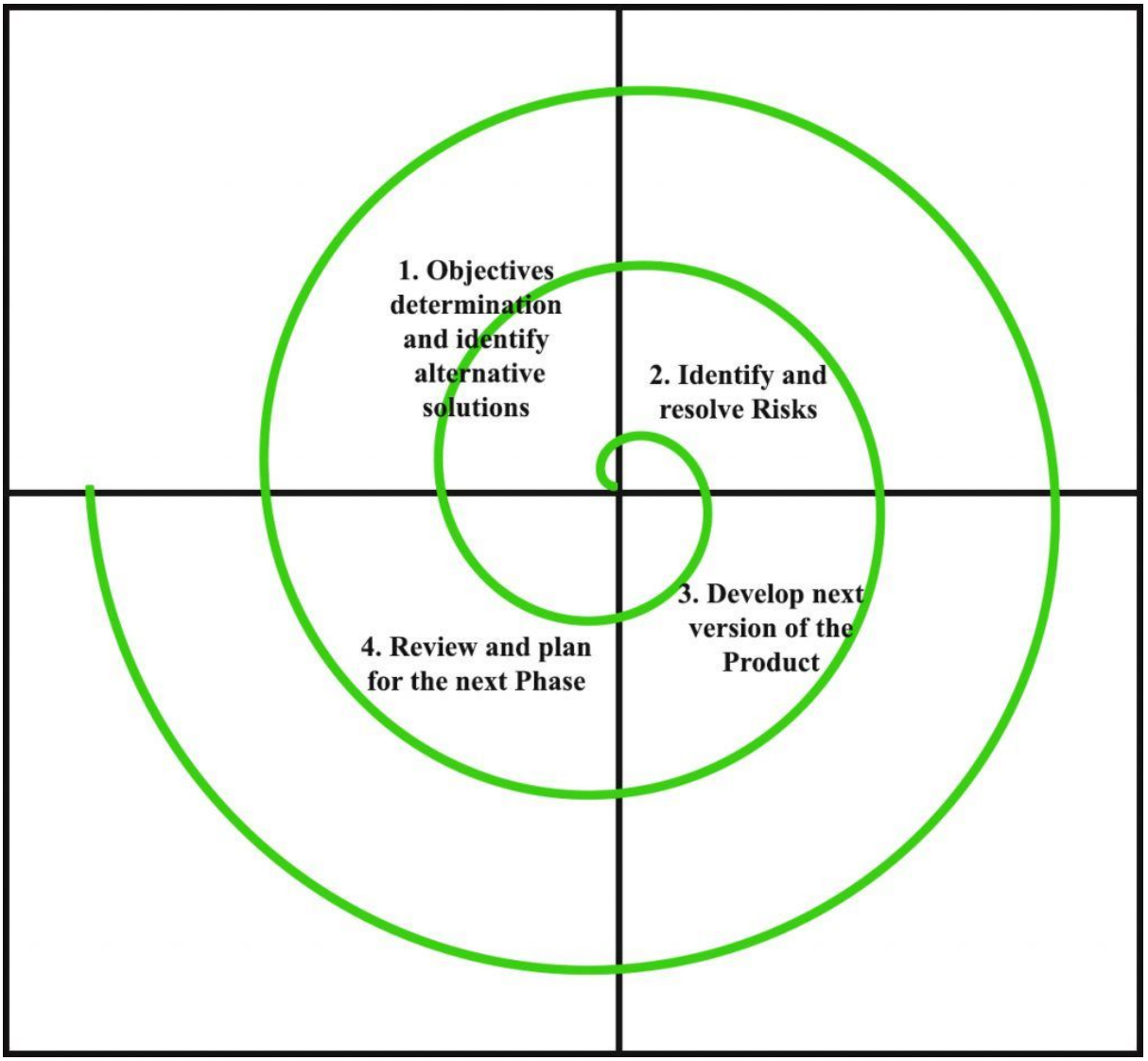
Scrum Workflow

In a team using Scrum, there are roles and a time limit for each life-cycle. The roles usually consist of a “Product Owner” - who is responsible for the initial planning, prioritising, and communication with the rest of the company, the “Scrum Master” - who oversees the entire sprint process, and “team members” - who carry out responsibilities to make the sprint possible such as producing code (3 Differences between Scrum and Kanban, 2015).

The self-imposed time limit for each life-cycle is called a “sprint”, and each can last an average of two weeks. Sprints are where the analysis, design, coding and testing of a functionality can be shipped; to optimize as much as possible, quick daily meetings are to review where each team member is, review meetings to identify, self-correct, and implement feedback, and finally at the end of each sprint - discuss what the next sprint will entail (Agile Development: A Quick Overview, 2017).

The Scrum Board uses a similar board to the Kanban Board but instead of focusing many tasks at once and allowing each task to be moved when complete, the entire team focuses on one task until the end of the sprint (3 Differences between Scrum and Kanban, 2015).

3.3.2. Spiral Development



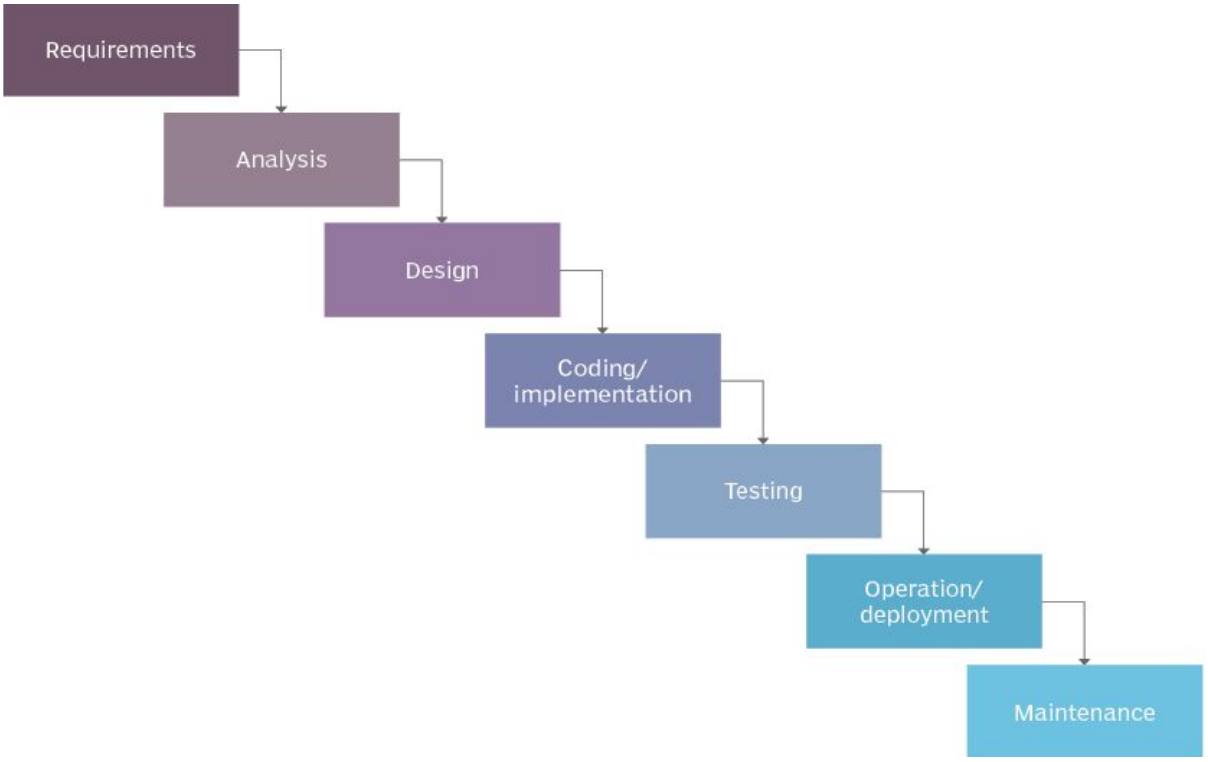
Software Engineering | Spiral Model (n.d.)

The Spiral development methodology has an emphasis on risk management. Each loop of the spiral is called a “phase”, and the number of phases can vary from project manager to project manager (Software Engineering | Spiral Model, n.d.).

The radius of the spiral at any point represent the expenses of the project, and the four quadrants define what goes on each Phase until moving onto the next Phase (Software Engineering | Spiral Model, n.d.):

1) Objectives determination and identify alternative solutions
2) Identify and resolve Risks
3) Develop next version of the Product
4) Review and plan for the next Phase

3.3.3. Waterfall Development



Waterfall Model (2019)

The Waterfall development is one of the more traditional production flow. Software is developed in large stages and is more efficient than using Agile or Spiral without the meetings, but less adaptable and the end product may not be what customers need or want. Each stage flows to the next with rarely any backtracking (Waterfall Model, 2019):

1) Requirements - the planning of any potential requirements, deadlines and guidelines for the project.
2) Analysis - the business logic that will guide production. Financial and technical resources are inspected.
3) Design - a document outlining all the potential requirements needed such as the programming language, hardware, data sources, architecture and services.
4) Coding / Implementation - the writing of source code, and designing user interface, along with the logo, images or models.
5) Testing - multiple testing processes before releasing to the public, such as quality assurance, unit, system, alpha, and beta testing.
6) Operation / Deployment - The product has passed all the software testing before deemed fully functional and ready for public use.
7) Maintenance - Fixing, improving and or adapting the final product with patch updates or releasing new versions.

3.4. Sampling Methodology

Sampling is to estimate the value of some attribute of a population. There are two sampling methodologies which are categorized as “non-probability samples” and “probability samples”. Participants in non-probability samples do not always know they have been chosen. Participants in probability samples know they have been chosen is a representative of the population (Survey Sampling Methods, n.d.).

3.4.1. Non-Probability Samples

There are two main types of non-probability sampling methods which are (Survey Sampling Methods, n.d.):

- Voluntary Sample - people who self-selected into the survey, and they often have a strong interest in the main topic of the survey.

- Convenience Sample - people who are within a certain physical area, such as interviewing shoppers at a supermarket.

3.4.2. Probability Samples

There are five main types of probability sampling methods which are (Survey Sampling Methods, n.d.):

- Simple Random Sample - one way to achieve this would be through a lottery system where each participant is assigned a unique number and lottery tickets are randomly picked.

- Systematic Random Sample - using the lottery example, instead of lottery tickets randomly picked, the first sample is from the first *n* elements on the total participants, and thereafter tickets are chosen every *nth* element.

- Stratified Sample - participants are divided into groups based on some characteristic, and then within each group, (often) a simple random sample is selected.

- Cluster Sample - participants are all assigned into only one group; eah group is called a “cluster”. A sample of clusters is chosen using (often) a simple random sample and participants within the chosen cluster is surveyed.

- Multi-Stage Sample - selecting a sample using a combination of sampling methods for each stage of sampling.

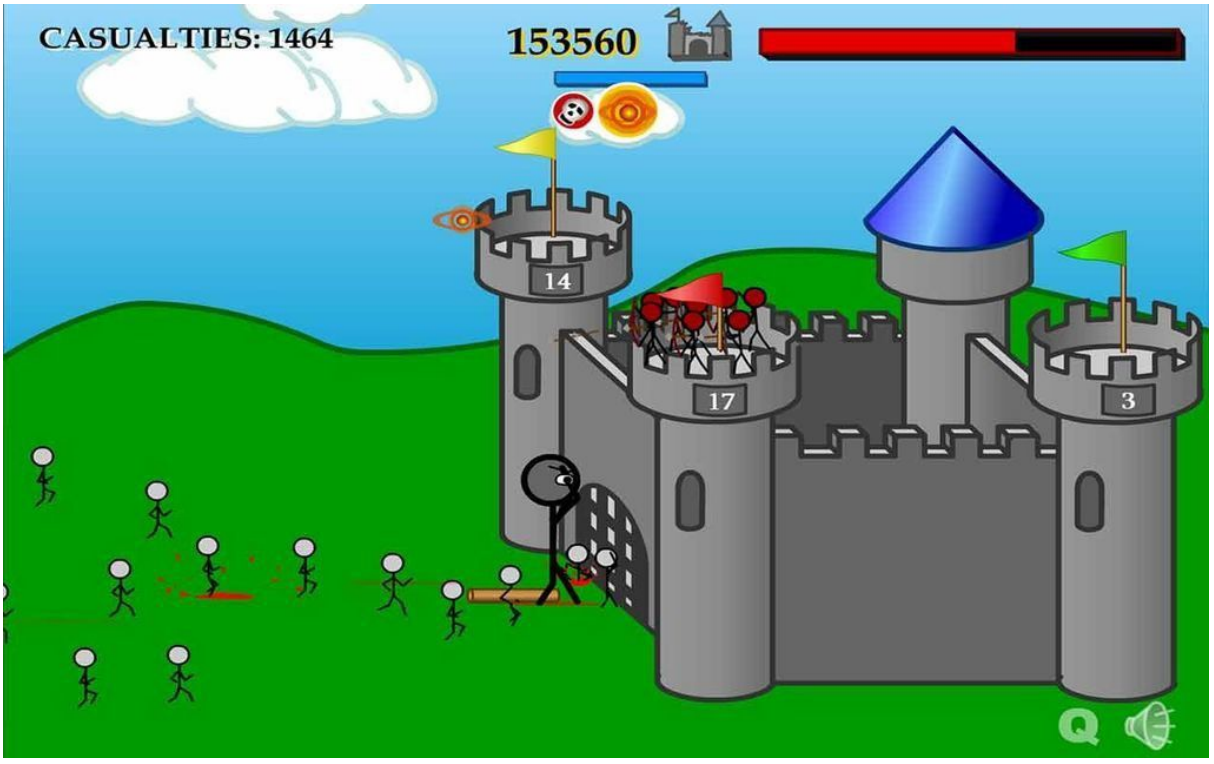
4. Game Design Document

4.1. Introduction

Atomic Attack is a game that will teach players the core concepts of the first 18 elements of the Periodic Table. The concepts include knowing the atomic numbers, their symbols, and what kind of interaction they could have in the real world.

4.2. Summary

The genre is under the category of Serious Games and Strategy, and it will be a game similar to the “Defend your Castle” series. However instead of defending the castle, the player is attacking it with units inspired by the first 18 elements of the Periodic Table.



Defend Your Castle (2008)

4.3. Target Audience

This game is targeted for the 1st Year Chemistry students of UWS but the game can be for everyone! As Chemistry is a core subject throughout school, players who play the game regardless of age will find it useful to learn.

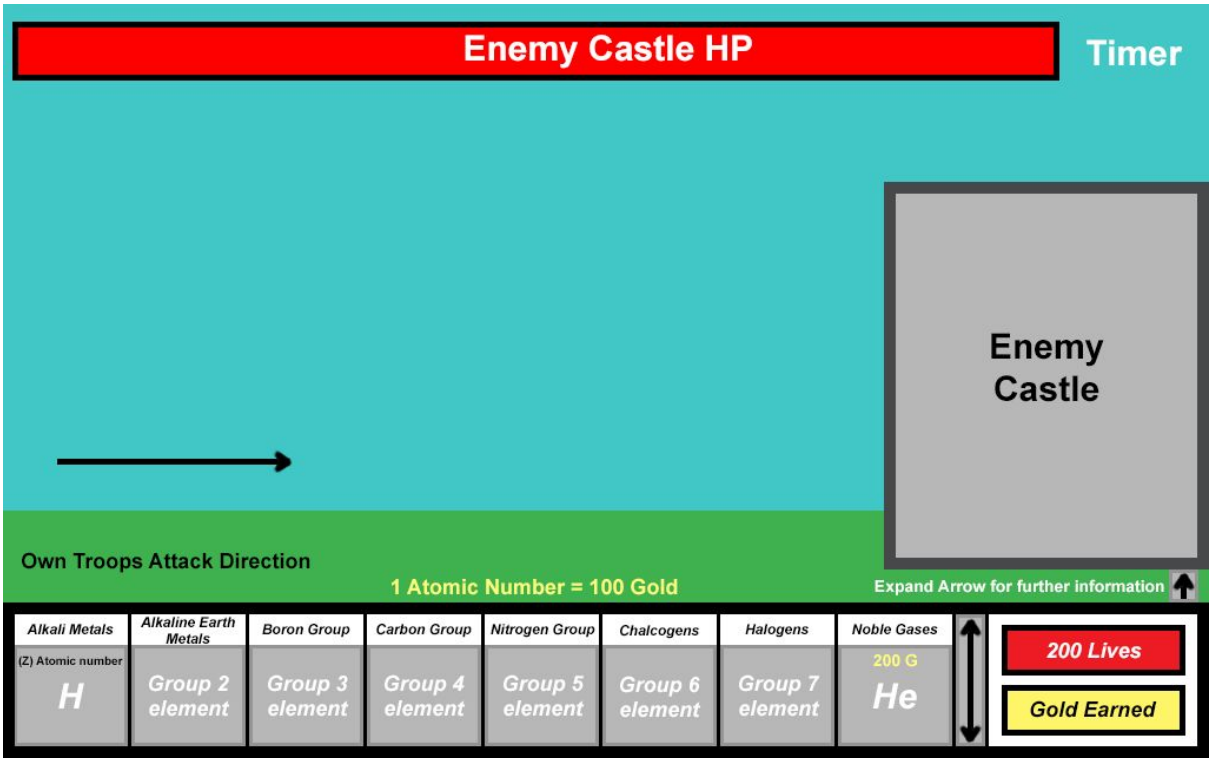
The experiment will test the learning objectives which are:

- Relate the symbol to the element for the first 18 elements of the Periodic Table.
- Learn the atomic number of each element.
- Understand what impact the use of the element could have in real-life.

4.4. GUI and Environment

As referenced in the above “Defend Your Castle” image, the GUI will look similar to that. However instead of defending the castle, the player is trying to destroy the castle in the quickest time possible, and a local leaderboard will appear at the end of each game - allowing competition between the player themself or friends.

The bottom bar which the player can scroll through the elements (which are set in Periodic Table style) can be expanded to see what element can do, how much each one “costs”, and additional information.



Proposed GUI and Environment

4.5. Player Mechanics

The player will not have any movement mechanics. On the player's side, friendly swordsmen will spawn periodically. The enemy castle side will also spawn their own swordsmen, in addition to units with guns.

The player can click on enemies to trip up the unit, disabling their movement or attack style. The player can click and hold to grab an enemy. The player can allow friendly swordsmen to kill the unit or increase its velocity above a threshold by being:

- Flicked up into the air.
- Dropped from above a certain height
- Thrown into the ground.

Enemy gunmen spawned on the castle have immunity for 10 seconds and cannot be touched by the player. If an enemy gunman survives the fall and if the unit is on the castle, the unit will shoot as normal; on the ground the unit will start moving and shooting. By killing the enemy units, gold will be earned and the player will focus on winning the war by sending out "special units" with the gold earned. The player can press the arrow to pause the game and read up on more information about the "special units".

4.6. Interactions and Consequences

If any enemy swordsmen get to the player's side, a life is lost. There is no time limit in completing the game, but a local high scoreboard will record the time taken to defeat the game and the player can continuously try to beat their personal best.

Each element will summon a group of "special units" or effect that will affect the game. The "special units" can be summoned, and they will have effects in par with real-life application uses of the element. Each special group will cost its atomic number multiplied by 100. For example - Hydrogen has an atomic number of 1 and will cost 100 gold, Sodium has an atomic number of 11 and will cost 1100 gold.

Symbol	Element	Proposed Interaction
H	Hydrogen	Special units will throw grenades a certain distance, even when attacked by enemy swordsmen.
He	Helium	Special units will fly in, dropping close to the castle.
Li	Lithium	Special units will shoot short-ranged tasers, temporarily disabling enemies.
Be	Beryllium	Special units will shoot fireworks, temporarily disabling ranged enemies.

B	Boron	Friendly swordsmen will temporarily have faster movement speed.
C	Carbon	Special units will carry shields which can protect other units in an area until it gets broken.
N	Nitrogen	The player can place barrels of nitrogen which will temporarily create a small suffocating area, and will make all melee units run away.
O	Oxygen	The player can place barrels of oxygen which will temporarily create a small area that magnifies explosions.
F	Fluorine	*Magnified Chlorine:* Will be greyed out until a star is collected for killing every 100 enemy units. The player drops a large bomb, exploding and covering the ground in an acidic area, damaging everyone, and will last until its debris is destroyed.
Ne	Neon	Will be greyed out until a star is collected for killing every 100 enemy units. A special large unit with low defense and fast movement will spawn. The unit will carry a lightsaber and will slice through everyone, including friendly units and attempt to block bullets.
Na	Sodium	*Magnified Lithium:* Special units will shoot long-ranged tasers, disabling enemies for a longer duration.
Mg	Magnesium	*Magnified Beryllium:* Special units will shoot white bright fireworks, disabling ranged enemies for a longer duration.
Al	Aluminium	*Magnified Boron:* Friendly swordsmen swords will temporarily have a white aura and increase their attack speed and attack damage.
Si	Silicon	*Magnified Carbon:* Special units will carry shields which can protect other units in an area until it gets broken. Shield lasts for longer and is larger.
P	Phosphorus	*Magnified Nitrogen:* The player can place barrels of phosphorus which will create a larger suffocating area, will make all melee units run away, and will last until destroyed.
S	Sulphur	*Magnified Oxygen:* The player can place barrels of sulphur which will create a larger area that magnifies explosions, will make all melee units run away, and will last until destroyed.
Cl	Chlorine	The player drops a small bomb, exploding and temporarily covering the ground in an acidic area, affecting everyone.

Ar	Argon	A special large unit with heavy defense and slow movement will spawn. The unit will carry a flamethrower, the flames affect everyone and burnt units will run away.

The special units will interact as above, and currently there is no plan for the elements to interact with each other or be combined, for example to combine one nitrogen and three hydrogen to make NH_3, ammonia gas.

Barrels placed will be priority target for enemy gunmen, and barrels cannot be stacked on top of each other, so the player cannot place 4 barrels of oxygen in one location and amplify an explosion four times.

4.7. Features Implemented

This will be a single-player endless strategy game released on Windows and Android mobile, with a local high scoreboard to encourage the player to improve on the current time taken to beat the game. If the game is developed further professionally, the game could be developed into a multiplayer game.

4.8. Game Structure

The game will be made with Unity. There will be a main screen, a menu option to see the local high scoreboard, the game scene itself and an informatic screen which will display extra information for each element.

Restart and pause buttons will be included and the expected experience of playing this game will be like playing “Defend the Castle” while learning a bit of chemistry!

4.9. Sound

The sound effects will engage the player in whichever action the player does, such as squishing when an enemy unit is tapped, or small screaming whenever they are thrown in the air. They will be small, simple and fun, taken from free sources like FreeSound or SoundBible, and edited with Audacity.

5. Game Implementation

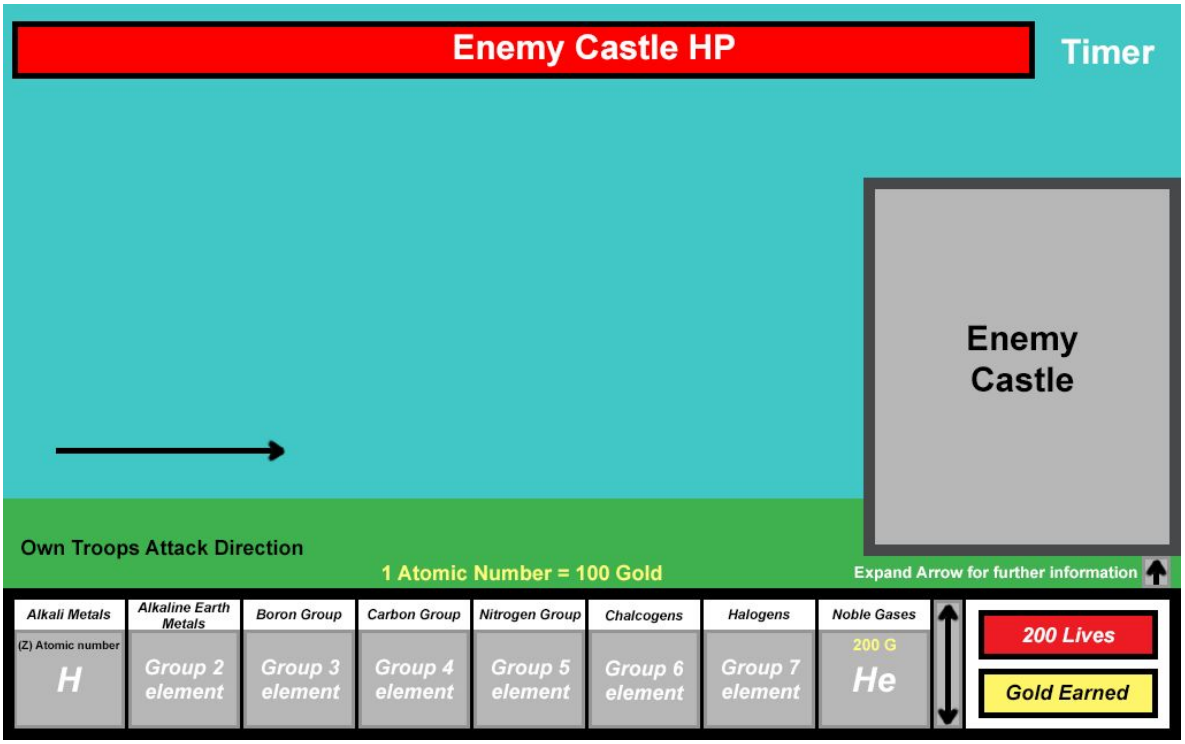
5.1. Development Methodology

The software development methodology used was Agile, with the Kanban workflow and GitHub for version control. Throughout the development process, the game underwent unit and alpha testing as whenever a new unit was created, the unit will be tested against all the other existing units in a one-versus-one scenario to make sure they were all working correctly. Questions were asked without revealing too much of the game to gain feedback from a non-developer's perspective and explanations were read over multiple times to make sure it was as clear as possible. Beta testing was not possible as players may learn about the scientific knowledge in the game and skew potential test results.

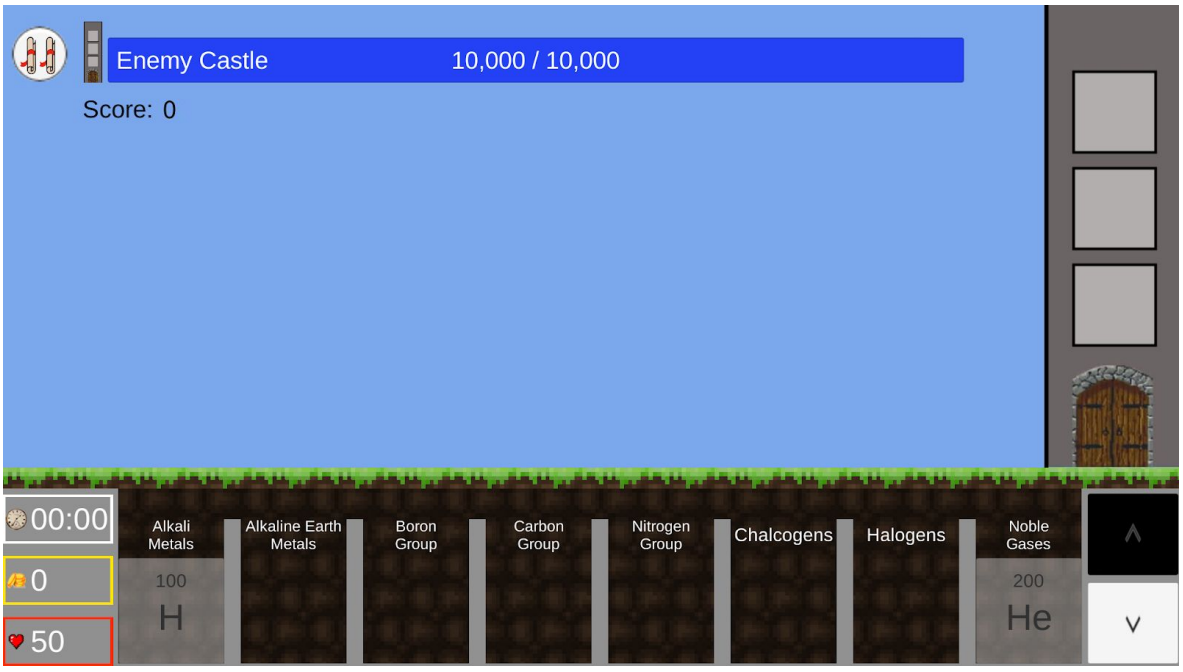
5.2. Game Development

5.2.1. GUI and Environment

What was initially proposed in the planning stages can evolve and improve as the game is being developed. There were not many deviations and mostly quality-of-life changes.



Proposed GUI and Environment



Actual GUI and Environment

The original idea for the castle was for the enemy units to spawn on the castle roof while more units spawned from the entrance. However as friendly units could be air-dropped in and could also be pushed into the air by explosive force - there was a pathing issue where if there were no enemy units on the roof, the friendly units could not find their way down, thus the castle changed to cover the entire screen height. The castle served as an additional barrier in which friendly units could not get past.

The timer, gold earned, and lives changed location due to as the player scrolled down the Periodic Table rows, their hand covered such information. The majority of people read from left to right and the relocation made the reading of information easier.

The up-down buttons increased in width. While it was easy to navigate with a mouse, gameplay was far better on a touchscreen device and having narrow buttons introduced problems of actually tapping the correct button while increasing misclicks.

The pause / help button moved as the original placement would be in the way of gameplay. The button activated the Help Menu and a diploma icon also highlights the scientific knowledge and educational parts in the game (see Appendix 11.1).

5.2.2. Player Mechanics

The player mechanics did not change. The 10 second immunity enemy gunmen receive after being spawned on the castle was removed, and gold is now earned for damaging the castle.

5.2.3. Interactions and Consequences

The number of lives was taken down from 200 to 50. The majority of proposed interactions stayed the same with Nitrogen, Oxygen, Phosphorus, and Sulphur changing the most. Due to how earlier elements introduced “click a button and its units will spawn”, having barrel placement was unintuitive without a tutorial.

On PC, the Y-axis would be highlighted according to the position of the mouse and with another mouse click - the barrel would drop from the sky onto the ground. On mobile, an axis could appear and be dragged about with no other action being allowed until the barrel was placed, but this took away precious seconds in a fast-paced game and hindered the player for not being able to throw away enemy units.

Element	Interaction
Hydrogen	Special units will throw grenades a certain distance, even when attacked by enemy swordsmen.
Helium	***Proposed*** Special units will fly in, dropping close to the castle. ***Change*** Instead of individual units flying in, a blimp is spawned carrying friendly swordsmen.
Lithium	Special units will shoot short-ranged tasers, temporarily disabling enemies.
Beryllium	Special units will shoot fireworks, temporarily disabling ranged enemies.
Boron	Friendly swordsmen will temporarily have faster movement speed.
Carbon	***Proposed*** Special units will carry shields which can protect other units in an area until it gets broken. ***Change*** Shielded units will not protect in an area. Due to how the targeting code was developed, shielded units will now stand in-front of other units.
Nitrogen	***Proposed*** The player can place barrels of nitrogen which will temporarily create a small suffocating area, and will make all melee units run away. ***Change*** A mist covering the whole map will slow down everyone’s movement speed and damage enemy units, lasting for 5 seconds.

Oxygen	***Proposed*** The player can place barrels of oxygen which will temporarily create a small area that magnifies explosions. ***Change*** A mist covering the whole map will magnify bombs, lasting for 12 seconds.
Fluorine	***Proposed*** *Magnified Chlorine:* Will be greyed out until a star is collected for killing every 100 enemy units. The player drops a large bomb, exploding and covering the ground in an acidic area, damaging everyone, and will last until its debris is destroyed. ***Change*** *Magnified Chlorine:* Will be greyed out until 200 enemy units are killed. The player will launch a rocket automatically aimed towards the castle, and after exploding will spawn a poisonous mist which will damage everyone, lasting for 5 seconds.
Neon	***Proposed*** Will be greyed out until a star is collected for killing every 100 enemy units. A special large unit with low defense and fast movement will spawn. The unit will carry a lightsaber and will slice through everyone, including friendly units and attempt to block bullets. ***Change*** Will be greyed out until 50 enemy swordsmen are killed. The unit will not attempt to block bullets.
Sodium	*Magnified Lithium:* Special units will shoot long-ranged tasers, disabling enemies for a longer duration.
Magnesium	*Magnified Beryllium:* Special units will shoot white bright fireworks, disabling ranged enemies for a longer duration.
Aluminium	***Proposed*** *Magnified Boron:* Friendly swordsmen swords will temporarily have a white aura and increase their attack speed and attack damage. ***Change*** Friendly swordsmen swords will not have a white aura and their attack damage is not increased.
Silicon	***Proposed*** *Magnified Carbon:* Special units will carry shields which can protect other units in an area until it gets broken. Shield lasts for longer and is larger.

	Change *Magnified Carbon:* The shielded unit will not protect in an area, and it will not be moved by any explosive force.
Phosphorus	***Proposed*** *Magnified Nitrogen:* The player can place barrels of phosphorus which will create a larger suffocating area, will make all melee units run away, and will last until destroyed. ***Change*** A mist covering the whole map will burn enemy units, lasting for 5 seconds. Burnt units will run faster.
Sulphur	***Proposed*** *Magnified Oxygen:* The player can place barrels of sulphur which will create a larger area that magnifies explosions, will make all melee units run away, and will last until destroyed. ***Change*** *Magnified Oxygen:* A mist covering the whole map will magnify bombs and will cause all enemy units to run away due to the smell produced, lasting for 5 seconds. Friendly units will wear gas masks to counter the smell.
Chlorine	***Proposed*** The player drops a small bomb, exploding and temporarily covering the ground in an acidic area, affecting everyone. ***Change*** The player will launch a rocket automatically aimed towards the castle, and after exploding will spawn a poisonous mist which will damage enemy units, lasting for 5 seconds. Friendly units will wear gas masks to counter the poison.
Argon	***Proposed*** A special large unit with heavy defense and slow movement will spawn. The unit will carry a flamethrower, the flames affect everyone and burnt units will run away. ***Change*** Additionally, the unit will not be moved by any explosive force.

This information is not presented in the Help Menu but each unit has its own statistics (see Appendix 11.2).

5.3. Bugs and Unsolvable Problems

There are several bugs that are extremely hard to fix, and some unsolvable due to it being a game engine problem and not code-wise.

A frequent bug that is easily replicable is the “forever Oxygen mist”. There are six different mists that can be spawned. Five mists last for 5 seconds - and to counter players pressing a lot of element buttons at once, a 5 second cooldown is put in place after buying any unit - while the Oxygen mist lasts for 12 seconds. While the Oxygen mist is already active, the player can buy Oxygen again; cooldowns were initialized with coroutines and reactivating a GameObject which is already active makes the coroutine glitch out. An easy fix will be instead of setting the GameObject as inactive / active, a new GameObject will spawn each time Oxygen is bought. Another harder fix would be to develop a new counting / timing method and not rely on coroutines.

Another non-frequent bug is that when the Fluorine / Chlorine rockets explode, the explosion damage is sometimes doubled or tripled. After the rockets explode, the corresponding mist is to instantiate once - however if the explosion damage is doubled or tripled, the mist also instantiates two or three times. Visually it is easy to spot as the enemy castle health drops more than usual and or the mist is thicker than usual. The player does not know the bug has occured when it does, however the code works perfectly and the only reason deduced is somehow the Explosion method and Instantiate mist method is called two or three times in the Update method.

There are two unsolvable problems. When testing to make sure the units work in a one-versus-one scenario, the enemy swordsman cannot damage either the friendly swordsman or the friendly Hydrogen unit. However during actual gameplay, the fault is unnoticeable due to there being multiple units on each side. It is still extremely strange as inheritance and polymorphism is used - the friendly swordsman and enemy swordsman is using the same code, but the friendly swordsman can damage the enemy swordsman while the enemy swordsman cannot damage the friendly swordsman? A UML Class Diagram was drawn (see Appendix 11.3).

The fault seems to be with the collision detection of the Unity Engine. This leads into the other problem of that the ground has the tag “Ground” and when any unit is in contact with the “Ground”, the boolean “Grounded” is checked. If a unit is pushed by an explosive force, or thrown by the player in a certain way, the unit can collide with the “Ground” but the boolean “Grounded” is not checked. This results in the unit either standing or lying down unable to do any other action until moved again by an external force.

5.4. Future Work

Considering the development of the game, Finite State Machines and Object Pooling could be used to improve the game's performance. However as there were not many different states a unit could do - running towards its target, attacking, or dying, the project itself was rather small - 24mb executable, and being unsure of how many prefabs would be spawned throughout an average game, Object.Instantiate was used.

Local high score, sound, and a proper menu system were not implemented. If the game was to be developed further, custom sprites and animations would be properly created hence no sprite will feel out of place with the current theme of the game. Local high score, sound, a tutorial and a proper menu system would be added. A better ending can be shown - such as when the castle reaches zero health, friendly units start cheering and enemy units start waving a surrender flag. Units will also be a bit larger and stronger units will be larger to emphasize their growth in power. Larger units will also mean the player will have an easier time grabbing and throwing.

In terms of coding and performance, Finite State Machines and Object Pooling will be added. More empty GameObject Managers will be added to keep track of gold, score, and unit statistics, so such values can be adjusted very quickly in one GameObject's inspector window instead of clicking through every single prefab. Score will be adjusted as currently the player's score increases with the amount of units bought, enemy units killed, and time played. However as one point of replayability is to lower the time played, it does not make sense to have a higher score as more time spent playing the game.

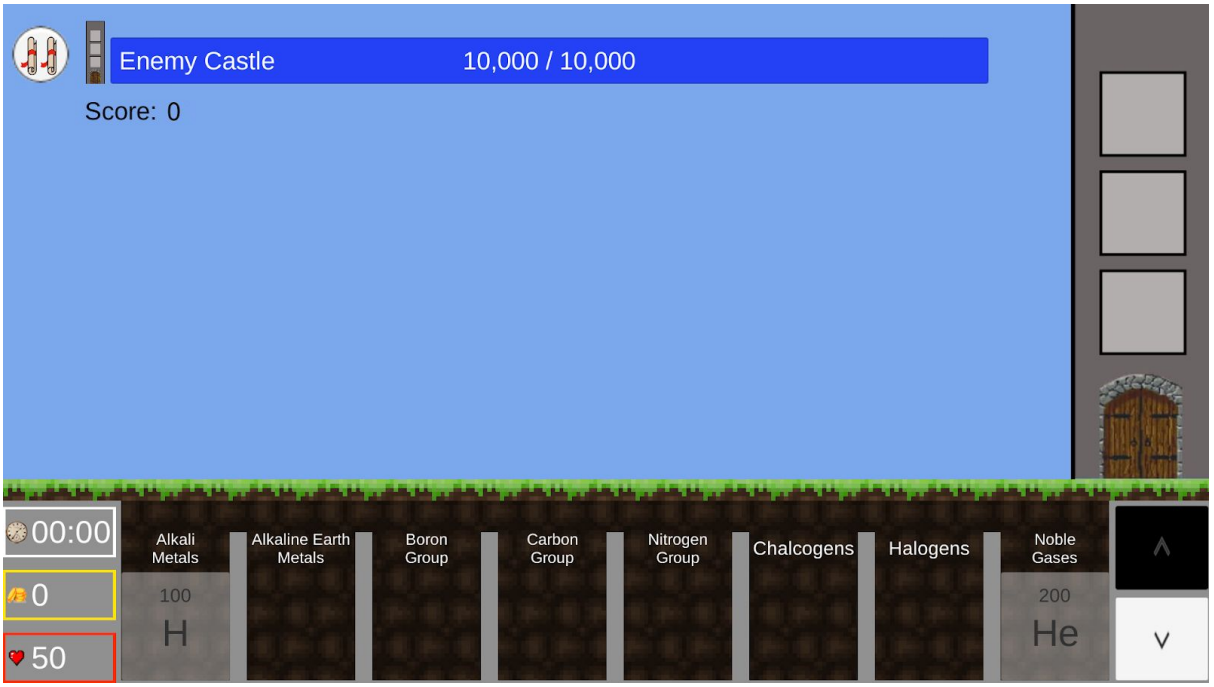
The targeting system will be rewritten with units having different threat levels. The higher the threat level, the higher priority to be killed. This will allow friendly ranged units to target enemy units on the castle and the custom sprites and animations will allow the gun to be rotated upwards or downwards, instead of the gun facing straight on and the bullet flying towards the target's location. More explosions will be added into the game - to make more use of Oxygen - and mists will last for a longer duration while disabling the appropriate element.

The easiest multiplayer component to add would be rankings across the different entries:

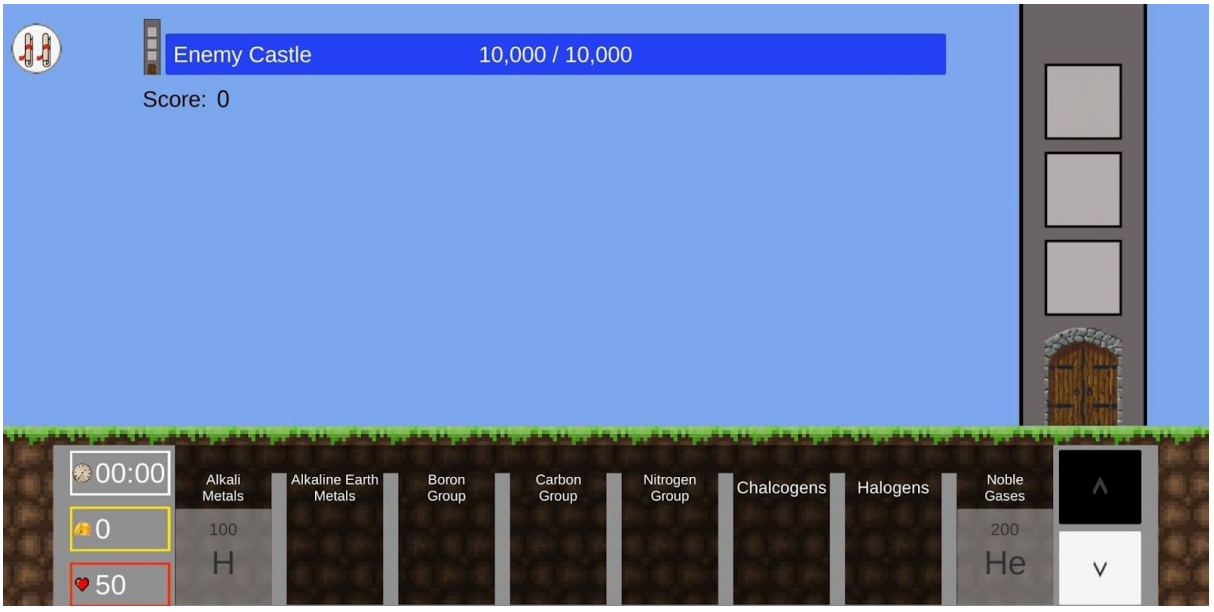
- Quickest time played.
- Highest score.
- Highest number of enemies killed.
- Least number of friends killed.

Another multiplayer component would be for a player to match against another player. Both players will each have their own tower and be able to grab enemy units while spawning their own.

The game does not scale correctly. The image below showing “Game Aspect Ratio 16:9” is how the game is meant to look. The majority of phones tested fit 16:9, but there were no smaller screen sizes to test out of all the participants with Android phones and the game does not scale correctly as shown in “Game Aspect Ratio 16:10”.



Game Aspect Ratio 16:9



Game Aspect Ratio 16:10

6. Testing

6.1. Preparation

The evaluation methodology will be quantitative research, obtaining discrete variables from primary sources. The type of methodology used and research design will be:

- Pre-Test
- Play the game
- Post-Test

Pre-Test Questions	Post-Test Questions
1) What is the atomic number of Hydrogen?	1) What does Boron do to the human body? (In-game effect)
2) What is the symbol for Lithium?	2) What is the symbol for Sodium?
3) What is the atomic number of Nitrogen?	3) What is the average temperature (°C) Argon burns at to create plasma?
4) What is the symbol for Sodium?	4) Neon is in a particular group of elements. What is the group called?
5) What is the atomic number of Carbon?	5) What is the atomic number of Oxygen?
6) Neon is in a particular group of elements. What is the group called?	6) What is Sulphur known for? (In-game effect)
7) What does the symbol “He” stand for?	7) What does the symbol “B” stand for?
8) What is the flame colour of Chlorine?	8) Red Phosphorus is found in… (In-game effect)
9) What does the symbol “B” stand for?	9) What is the symbol for Magnesium?
10) What is the average temperature (°C) Argon burns at to create plasma?	10) What is the flame colour of Chlorine?

The Pre-Test was built in mind of not being too easy neither too hard for either a Chemistry or non-Chemistry student. Scientific information that was used to theorise and build the upgraded units were gathered to create both tests. Both tests have the same format of 10 questions, with 5 questions from the Pre-Test repeated across in the Post-Test to gather two sets of results: the score of repeated questions, and the overall score. The Post-Test's singular questions were noticeably harder than the Pre-Test's singular questions.

6.2. Participants

The sampling method will be a non-probability voluntary sample as the participants will either be 1st Year Chemistry students of UWS or students interested in the experiment and game.

Participants will be asked to read through the Plain Language Statement (see Appendix 11.4) to understand the purpose of the study, what the experiment entails, and what will happen to the results recorded. Every individual will also read through the Participant Consent Approval Form (see Appendix 11.5) to signify they have read through the Plain Language Statement and give permission to begin the experiment.

Before the Pre-Test participants will also be asked to self-evaluate their knowledge on the first 18 elements of the Periodic Table on a scale of 1-5 with "1" being the worst and "5" being the best. After the Post-Test, participants were asked if they would play the game again on a scale of 1-5 with "1" being the worst and "5" being the best. Both results were recorded.

6.3. Data Collection

The Pre-Test and Post-Test were created using Google Sheets, and their results recorded within the appropriate forms. The only identifying information asked was the participant's name. The results were compiled into a Google Excel document, and the name used to identify which result was which will then be omitted from this dissertation.

7. Analysis

There were 40 participants in total, with the majority of participants coming from a non-chemistry background. The results presented below will be split into two categories with each test - a mark out of 5 for the repeated questions, and a mark out of 10 for the full test. The Pre-Test scores and Post-Test scores will be compared and an average percentage increase or decrease will shown.

A random sample of 6 participants' answers will be chosen and shown in the Appendix (see Appendix 11.6), and there will be an even spread between the two categories - "non-Chemistry background" and "Chemistry background".

Number	Self-Evaluation (/ 5)	Repeated Questions Score			Total Questions Score			Play Again? (/ 5)
		Pre-Test (/ 5)	Post-Test (/ 5)	Change	Pre-Test (/ 10)	Post-Test (/ 10)	Change	
01	5	3	5	+2	7	8	+1	5
02	3	3	3	0	6	4	-2	5
03	1	0	0	0	3	2	-1	5
04	4	0	1	+1	0	2	+2	4
05	2	1	4	+3	4	5	+1	5
06	2	1	4	+3	4	5	+1	4
07	2	1	4	+3	4	6	+2	4
08	3	3	3	0	6	5	-1	4
09	1	0	3	+3	3	5	+2	4
10	3	0	0	0	2	1	-1	4
11	2	3	3	0	6	5	-1	5
12	1	0	1	+1	0	1	+1	5
13	1	0	1	+1	0	2	+2	4
14	3	1	3	+2	3	3	0	4
15	4	2	3	+1	4	5	+1	3
16	2	2	3	+1	4	3	-1	5
17	2	1	1	0	2	1	-1	4
18	2	0	0	0	1	1	+1	3
19	4	3	3	0	6	5	-1	5
20	1	0	1	+1	0	4	+4	3
21	5	5	5	0	8	10	+2	5
22	2	0	4	+4	2	7	+5	5
23	1	0	4	+4	2	5	+3	4
24	3	2	4	+2	5	8	+3	5
25	5	3	5	+2	6	10	+4	5
26	3	3	4	+1	7	6	-1	5
27	2	1	2	+1	4	4	0	5
28	2	2	4	+2	4	6	+2	4
29	2	3	4	+1	6	5	-1	5
30	1	0	2	+2	1	3	+2	5
31	1	0	2	+2	2	4	+2	5
32	2	0	2	+2	2	4	+2	5
33	3	1	4	+3	3	6	+3	5
34	2	2	3	+1	4	5	+1	5
35	1	0	2	+2	2	4	+2	5
36	1	0	2	+2	1	4	+3	5
37	1	0	3	+3	2	4	+2	5
38	2	4	4	0	7	5	-2	5
39	2	3	4	+1	6	6	0	5
40	2	3	4	+1	6	7	+1	3

The stated hypothesis was:

H_0: The student's score will not change after playing the video game.
H_1: The student will score higher in revising the basic topic after playing the video game.

The rating participants gave the game was an average of 4.5 / 5. Using inferential analysis, out of the "Repeated Questions Score" changes - 10 participants scored with no change, and the remaining 30 participants scored positively. There was an average increase of 2.9%.

Out of the "Total Questions Score" - 14 participants scored with either no change or negatively, and the remaining 26 participants scored positively. There was an average increase of 1.025%.

Using the discrete variables obtained from primary sources, the null hypothesis (H_0) is rejected and the alternative hypothesis (H_1) is accepted.

Limitations

There were several limitations in the experiment with the most glaring one of having too much information to process in too short amount of time. There were too many elements to choose from, and once participants found an element they liked, they usually chose that particular element or elements again and again without testing the other elements. Some participants even completed the game while ignoring the elements in its entirety - a valid way to play but defeated the whole "read through the element's statistics" facet.

Participants also did not know if and what questions would be repeated, therefore skimmed through the Help Menu (see Appendix 11.1) before choosing the elements they enjoyed using the most. The majority of participants did not enjoy reading and thus had a difficult time playing the game in the beginning. However after explaining, demonstrating, and restarting the game, participants enjoyed playing the game as it was interactive and liked throwing helping units around.

One way to avoid the "too much information" limitation would be to have participants do the Pre-Test, play the game, do the Post-Test immediately afterwards, and then do another different Post-Test in a week's time to see how much information was retained from initial playthrough and repeated playthrough. Despite the solution, it would be very hard to monitor how often players actually played and how much they read.

Another limitation was that there was no sound which reduced the amusement and engagement levels. Participants also found the game easier to play in mobile than on PC, and since the game was built for only Android, Apple users were left out in having the game installed on their personal device.

8. Conclusion

The results of the experiment showed that the game produced was effective in teaching the topic about the first 18 elements of the Periodic Table. In the majority of participants, the learning objectives were achieved and several participants reported back after some days saying they have been playing the game in their spare time and have picked up on the information written in the Help Menu (see Appendix 11.1).

Following the self-constructed guideline to make a state-of-the-art serious game, not one participant gave up or was bored in playing the game and they were all fully engaged for their duration of gameplay. Even with the “too much information” limitation, the results were similar to the findings in the literature review, especially with the chemistry games found in the market research. Participants who paused to read through what the units were not distracted by the pause in gameplay for they were considering what to use, and the ones who did not read as thoroughly could reflect back to the game’s experience and what effect was produced to answer questions they were struggling on in the Post-Test.

If the game is to be developed further professionally, all the issues in Section 5.4 would be addressed and most likely developed further with more and better ideas such as having more element combinations. The issues in Section 5.4 solely describe how game could be improved in its current standing.

9. Critical Self Appraisal

It was hard to get started because of the thought of reading research papers and referencing in the literature review; and without doing the literature review, I could not complete the other sections. Once I finally sat down and completed the literature review, I could get to what I really wanted to do - the game design document and making the game.

Balancing the scientific knowledge available, a game was not too easy or too hard to make, while still making the game fun and interactive was difficult. Although I had the help of friends and lectures in Chemistry, their time was still to be respected. Several ideas and iterations were thrown around and discarded until I came up with the current idea.

With the late start in literature review and juggling other courseworks, I was left with two months to make the game. The two months were enough time to make the game, extremely enjoyable, and I learnt a lot while simultaneously struggling over the simplest problems that had no solution in sight.

The only thing I regret is not adding in sound which would have massively increased the engagement and entertainment levels of participants playing the game. My planning had left a single day to implement sound and despite the fact it was working, it wasn’t working the way I envisioned it to be and resulted in being distracting and discordant.

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11.1. Help Menu

How far Blue is thrown is how much damage is dealt !
Don't let Blue on Red's (left) side of the map.
You will lose a life and you only have 50 lives !

Alkali Metals	Alkaline Earth Metals	Boron Group	Carbon Group	Nitrogen Group	Chalcogens	Halogens	Noble Gases
100 H							200 He
300 Li	400 Be	500 B	600 C	700 N	800 O	900 F	1000 Ne
1100 Na	1200 Mg	1300 Al	1400 Si	1500 P	1600 S	1700 Cl	1800 Ar

The user interface is designed like the Periodic Table.
There is the "Group Name" at the top of each column.
Gold Cost correlates with the Atomic Number.

100
H

- Element : Hydrogen
- Atomic Number : 1
- Relative Mass : 1.00u
- Group Name : Alkali Metals

Cost : 100g
Spawns : 3 x Grenadiers.
Property : Explosive mixtures with Oxygen.

200
He

- Element : Helium
- Atomic Number : 2
- Relative Mass : 4.00u
- Group Name : Noble Gases

Cost : 200g
Spawns : 1 x BLIMP.
- Releases 5 x Swordsmen.
Property : The second lightest element.

300
Li

- Element : Lithium
- Atomic Number : 3
- Relative Mass : 6.94u
- Group Name : Alkali Metals

Cost : 300g
Spawns : 2 x Small Tasers.
Property : Lithium-ion batteries are rechargeable.

400
Be

- Element : Beryllium
- Atomic Number : 4
- Relative Mass : 9.01u
- Group Name : Alkaline Earth Metals
- Cost : 400g
- Spawns : 2 x Small Flashbangs.
- Property : High thermal conductivity.

500
B

- Element : Boron
- Atomic Number : 5
- Relative Mass : 10.81u
- Group Name : Boron Group
- Cost : 500g
- Effect : Increases movement speed.
- Property : Helps muscle growth.

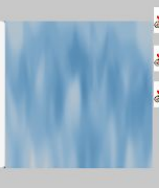
600
C

- Element : Carbon
- Atomic Number : 6
- Relative Mass : 12.01u
- Group Name : Carbon Group
- Cost : 600g
- Spawns : 2 x Light Shields.
- Property : Its hardness changes according to its crystalline structure.

700
N

- Element : Nitrogen
- Atomic Number : 7
- Relative Mass : 14.00u
- Group Name : Nitrogen Group
- Cost : 700g
- Spawns : Freezing Mist damages Enemies.
- Property : Liquid nitrogen causes rapid freezing.

800
O



- Element : Oxygen
- Atomic Number : 8
- Relative Mass : 15.99u
- Group Name : Chalcogens
- Cost : 800g
- Spawns : Magnifying explosions Mist.
- Property : Combine with Hydrogen!

900
F

- Element : Fluorine
- Atomic Number : 9
- Relative Mass : 18.99u
- Group Name : Halogens
- Cost : 900g + 200 Enemies
- Spawns : Big Rocket and Poison damages all.
- Property : Stronger version of Chlorine.
- Flame Colour : Pale Yellow-Green.

1000
Ne

- Element : Neon
- Atomic Number : 10
- Relative Mass : 20.17u
- Group Name : Noble Gases
- Cost : 1000g + 50 Enemy Swordsmen
- Spawns : Jedi Master who damages all.
- Property : Electricity is applied to ionize Neon gas causing it to emit light.

1100
Na

- Element : Sodium
- Atomic Number : 11
- Relative Mass : 22.98u
- Group Name : Alkali Metals
- Cost : 1100g
- Spawns : 1 x Big Tasers.
- Property : Stronger version of Lithium.
- Flame Colour : Yellow.

1200
Mg

- Element : Magnesium
- Atomic Number : 12
- Relative Mass : 24.30u
- Group Name : Alkaline Earth Metals
- Cost : 1200g
- Spawns : 1 x Big Flashbangs.
- Property : Stronger version of Beryllium.
- Flame Colour : White.

1300
Al

- Element : Aluminium
- Atomic Number : 13
- Relative Mass : 26.98u
- Group Name : Boron Group
- Cost : 1300g
- Effect : Increases attack speed.
- Property : Soft, non-magnetic and ductile metal.
- Flame Colour : Silver-White.

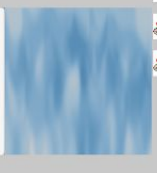
1400
Si

- Element : Silicon
- Atomic Number : 14
- Relative Mass : 28.08u
- Group Name : Carbon Group
- Cost : 1400g
- Spawns : 1 x Heavy Shield.
- Property : Stronger version of Carbon.
- Upgrade Colour : Blue-Grey.

1500
P

- Element : Phosphorus
- Atomic Number : 15
- Relative Mass : 30.97u
- Group Name : Nitrogen Group
- Cost : 1500g
- Spawns : Burning Mist damages Enemies.
- Property : Found in the tips of safety matches.
- Flame Colour : Bluish-Green.

1600
S



- Element : Sulphur
- Atomic Number : 16
- Relative Mass : 32.06u
- Group Name : Chalcogens
- Cost : 1600g
- Spawns : Magnifying explosions and Smelly Mist.
- Property : Infamous for its smell.
- Flame Colour : Blue.

1700
Cl

- Element : Chlorine
- Atomic Number : 17
- Relative Mass : 35.43u
- Group Name : Halogens
- Cost : 1700g
- Spawns : Small Rocket and Gas Masks on Allies.
- Property : Poisonous, and in swimming pools!
- Flame Colour : Green.

1800
Ar

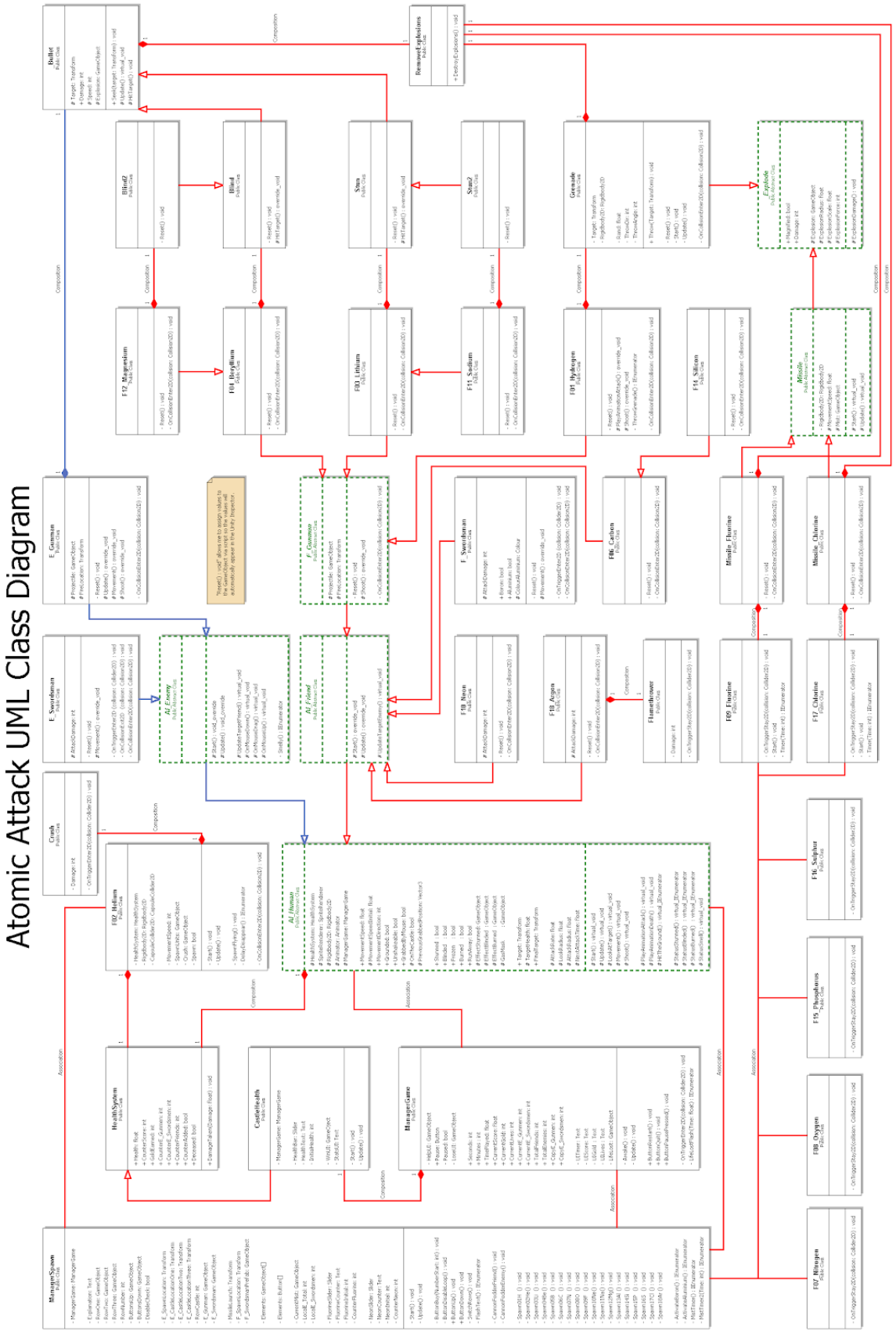
- Element : Argon
- Atomic Number : 18
- Relative Mass : 39.94u
- Group Name : Noble Gases
- Cost : 1800g
- Spawns : Flamethrower who damages all.
- Property : Creates plasma with ICP-OES at an average of 8000°C.

11.2. Unit Statistics

AoE means “Area of Effect”.

	(Integers == Green)			Move	Attack	Look	Attack	Attack	Projectile	Projectile	Castle HP = 10,000. AoE >= 5.00 can hit Castle Units		
	Cost	Score	Health	Speed	Rate (p / s)	Radius	Radius	Damage	Type	Speed	Effect	Duration (sec)	
E_Swordsman	Every 2 sec	2000	100.00	1.20	1.00	3.00	0.85	1	Sword	/	/	Till Dead	
F_Swordsman	Every 4 sec	/	50.00	1.20	1.00	3.00	0.85	1	Sword	/	/	Till Dead	
E_Gunman	Every 2 sec	100	75.00	1.00	0.75	3.00	3.00	2	Gun	15	/	Till Dead	
F_Gunman	Not using, Parent class for Elements ↓			1.00	0.75	3.00	3.00	2	Gun	15	/	Till Dead	
(1) Hydrogen	100.00	100	100.00	1.00	1.40	3.00	1.75	5	Grenade	Angle = 90	AoE Damage	Till Dead	AoE = 0.25
(2) Helium	200.00	200	100.00	1.00	/	/	/	150	F_Swordsmen	/	Floating	Till Dead	
(3) Lithium	300.00	300	100.00	1.00	2.00	3.00	2.25	5	Gun	10	Stun	1	
(11) Sodium	1,100.00	1100	200.00	1.20	0.75	3.50	3.50	20	Gun	15	Damage + Stun	1	
(4) Beryllium	400.00	400	100.00	1.00	2.00	3.00	2.75	5	Gun	10	Blind	2	
(12) Magnesium	1,200.00	1200	200.00	1.20	0.75	4.00	4.00	20	Gun	15	Damage + Blind	2	
(5) Boron	500.00	500	/	2.00	/	/	/	/	/	/	Move Speed++	5	
(13) Aluminium	1,300.00	1300	/	/	0.50	/	/	/	/	/	Attack Speed++	5	
(6) Carbon	600.00	600	350.00	0.90	/	3.00	0.75	/	Shield		Shield	Till Dead	
(14) Silicon	1,400.00	1400	1000.00	1.00	/	3.00	0.65	/	Shield		Unshakeable + Shield	Till Dead	
(7) Nitrogen	700.00	700	/	0.25	DoT		Whole Map	1	Mist		Frozen	5	
(15) Phosphorus	1,500.00	1500	/	2.00	DoT		Whole Map	2	Mist		Burned	5	
(8) Oxygen	800.00	800	/	/	/	/	Whole Map	/	Mist		Explosions ++	12	
(16) Sulphur	1,600.00	1600	/	/	/	/	Whole Map	/	Mist		Run Away Smell + Explosions ++	5	
(09) Fluorine	900.00	1800	/	/	Bomb + DoT	/	Whole Map	250 + 2	Rocket + Mist		Poison	5	AoE = 5.00
(17) Chlorine	1,700.00	1700	/	/	Bomb + DoT	/	Whole Map	150 + 1	Rocket + Mist		Friendly Gas Masks + Poison	5	AoE = 5.00
(10) Neon	1,000.00	2000	50.00	1.40	1.40	3.00	1.00	100	None	/	Lightsaber	Till Dead	
(18) Argon	1,800.00	1800	125.00	0.80	Continuous	3.00	3.00	1	Flamethrower	Continuous (0)	Burn	Till Dead	
										Every Fixed Update			

11.3. UML Class Diagram



11.4. Plain Language Statement

UNIVERSITY OF THE WEST of SCOTLAND

Plain Language Statement Information Sheet

School: School of Computing, Engineering and Physical Sciences

Project Title: Serious Games in Chemistry

Computing Hons Project Student: Yu-Ching Ho
Email address:

Computing Hons Project Supervisor: Dr. Mario Soflano
Email address: mario.soflano@uws.ac.uk
Contact number: 0141 848 3311

Computing Hons Project Module Coordinator: Dr. Mark Stansfield
Email address: mark.stansfield@uws.ac.uk
Contact number: 0141 848 3963

Programme Title: BSc (Hons) in: Computer Games Development

Dear participant,

You are being invited to take part in my research study – as above. Before you decide it is important for you to understand why the research is being done and what will be involved. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information. Please take your time in deciding if you wish to take part and thank you for reading this.

What is the purpose of the study?
The purpose of the study is to see whether a game can be a tool to assist in learning as well as improving knowledge retention in Chemistry. The subject area is the first 18 elements of the Periodic Table. If the participant has no prior knowledge of the subject area, the game is there to build a fun introduction and foundation to Chemistry. If the participant does know the subject area, the game is there as a revision tool and potentially learn something new outside their curriculum. In both cases, hopefully the participant will want to learn more and undertake extra-curricular research.

Why have I been chosen?
The target participants for this experiment are university students who are interested in learning Chemistry or using the game as a revision tool.

Do I have to take part?
It is up to you to decide whether or not to take part. If you do decide to take part you will be given this information sheet to keep and be asked to sign a consent form. If you decide to take part you are still free to withdraw at any time and without giving a reason. A decision not to participate will not affect your grades in any way.

What will happen to me if I take part?
As a participating subject you will be asked to do a small quiz of ten questions to rate your knowledge of Chemistry beforehand. You will be asked to play the game on PC or mobile (your preference) and the game will take an average of 10 minutes to play. After the game, another small quiz of ten questions is to be completed. The second test will be harder and slightly different from the first test. Both test results will be compiled to see if there has been any change between the results.

Will my taking part in this study be kept confidential?
All information, which is collected, about you during the course of the research will be kept strictly confidential. You will be identified by an ID number or letter and any information about you will have your name, address and all other identifiable details removed so that you cannot be recognised from it.

What will happen to the results of the research study?
A bound copy of the completed Hons Project report may be stored at the University of the West of Scotland library (subject to approval).

Who is organising the research?
The School of Engineering and Computing at the University of the West of Scotland is organising this Computing Hons Project.

Who has reviewed the study?
The project has been reviewed by the student's supervisor, moderator, year leader, module coordinator and chair of the School of Engineering and Computing Ethics Committee.

Contact for Further Information
For further information please contact:
Computing Hons Project Student: Yu-Ching Ho
Email address:

Alternatively, if participants have any concerns regarding the conduct of the research project please contact the School of Computing, Engineering and Physical Sciences Ethics Committee Chair by contacting Dr John Hughes – john.hughes@uws.ac.uk

Thank you for taking part in this study.

UWS UNIVERSITY OF THE WEST of SCOTLAND

School of Computing, Engineering and Physical Sciences

PARTICIPANT CONSENT FORM

Title of Project: Serious Games in Chemistry

Name of Researcher: Yu-Ching Ho

1. I confirm that I have read and understand the Plain Language Statement for the above study and have had the opportunity to ask questions.
2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason.
3. I understand that I will be asked questions and my responses will be recorded, but that I will not be identified by name in any resulting published work. .
4. I agree / do not agree (delete as applicable) to take part in the above study.

Name of Participant Date Signature

Researcher Date Signature

1 copy for subject; 1 copy for researcher

11.6. Answers - Participant 01 (Chemistry)

Pre-Test Questions	Answer
How would you rate your knowledge on the first 18 elements of the Periodic Table? ("1" is the worst, "5" is the best)	5
1) What is the atomic number of Hydrogen?	1 ✓
2) What is the symbol for Lithium?	Li ✓
3) What is the atomic number of Nitrogen?	7 x
4) What is the symbol for Sodium?	Na ✓
5) What is the atomic number of Carbon?	12 x
6) Neon is in a particular group of elements. What is the group called?	Noble Gases ✓
7) What does the symbol “He” stand for?	Helium ✓
8) What is the flame colour of Chlorine?	Purple x
9) What does the symbol “B” stand for?	Boron ✓
10) What is the average temperature (°C) Argon burns at to create plasma?	500 x

Post-Test Questions	Answer
1) What does Boron do to the human body? (In-game effect)	Help muscles growth ✓
2) What is the symbol for Sodium?	Na ✓
3) What is the average temperature (°C) Argon burns at to create plasma?	8000 ✓
4) Neon is in a particular group of elements. What is the group called?	Noble Gases ✓
5) What is the atomic number of Oxygen?	6 x
6) What is Sulphur known for? (In-game effect)	Bad smell ✓
7) What does the symbol “B” stand for?	Boron ✓
8) Red Phosphorus is found in… (In-game effect)	x
9) What is the symbol for Magnesium?	mg ✓
10) What is the flame colour of Chlorine?	green ✓
Would you play the game again? ("1" is the worst, "5" is the best, Honest answer)	5

11.7. Answers - Participant 21 (Chemistry)

Pre-Test Questions	Answer
How would you rate your knowledge on the first 18 elements of the Periodic Table? ("1" is the worst, "5" is the best)	5
1) What is the atomic number of Hydrogen?	1 ✓
2) What is the symbol for Lithium?	Li ✓
3) What is the atomic number of Nitrogen?	9 x
4) What is the symbol for Sodium?	Na ✓
5) What is the atomic number of Carbon?	8 x
6) Neon is in a particular group of elements. What is the group called?	Noble Gases ✓
7) What does the symbol “He” stand for?	Helium ✓
8) What is the flame colour of Chlorine?	Green ✓
9) What does the symbol “B” stand for?	Boron ✓
10) What is the average temperature (°C) Argon burns at to create plasma?	8000 ✓

Post-Test Questions	Answer
1) What does Boron do to the human body? (In-game effect)	Muscle growth ✓
2) What is the symbol for Sodium?	Na ✓
3) What is the average temperature (°C) Argon burns at to create plasma?	8000 ✓
4) Neon is in a particular group of elements. What is the group called?	Noble gases ✓
5) What is the atomic number of Oxygen?	8 ✓
6) What is Sulphur known for? (In-game effect)	Very smelly ✓
7) What does the symbol “B” stand for?	Boron ✓
8) Red Phosphorus is found in… (In-game effect)	Matches ✓
9) What is the symbol for Magnesium?	Mg ✓
10) What is the flame colour of Chlorine?	Green ✓
Would you play the game again? ("1" is the worst, "5" is the best, Honest answer)	5

11.8. Answers - Participant 25 (Chemistry)

Pre-Test Questions	Answer
How would you rate your knowledge on the first 18 elements of the Periodic Table? ("1" is the worst, "5" is the best)	5
1) What is the atomic number of Hydrogen?	1 ✓
2) What is the symbol for Lithium?	Li ✓
3) What is the atomic number of Nitrogen?	5 x
4) What is the symbol for Sodium?	Na ✓
5) What is the atomic number of Carbon?	12 x
6) Neon is in a particular group of elements. What is the group called?	Noble Gases ✓
7) What does the symbol “He” stand for?	Helium ✓
8) What is the flame colour of Chlorine?	Orange x
9) What does the symbol “B” stand for?	Boron ✓
10) What is the average temperature (°C) Argon burns at to create plasma?	3000 x

Post-Test Questions	Answer
1) What does Boron do to the human body? (In-game effect)	Speed ✓
2) What is the symbol for Sodium?	Na ✓
3) What is the average temperature (°C) Argon burns at to create plasma?	8000 ✓
4) Neon is in a particular group of elements. What is the group called?	Noble gases ✓
5) What is the atomic number of Oxygen?	8 ✓
6) What is Sulphur known for? (In-game effect)	Smelly ✓
7) What does the symbol “B” stand for?	Boron ✓
8) Red Phosphorus is found in… (In-game effect)	Matches ✓
9) What is the symbol for Magnesium?	Mg ✓
10) What is the flame colour of Chlorine?	Green ✓
Would you play the game again? ("1" is the worst, "5" is the best, Honest answer)	5

11.9. Answers - Participant 02 (Non-Chemistry)

Pre-Test Questions	Answer
How would you rate your knowledge on the first 18 elements of the Periodic Table? ("1" is the worst, "5" is the best)	3
1) What is the atomic number of Hydrogen?	1 ✓
2) What is the symbol for Lithium?	Li ✓
3) What is the atomic number of Nitrogen?	4 x
4) What is the symbol for Sodium?	Na ✓
5) What is the atomic number of Carbon?	16 x
6) Neon is in a particular group of elements. What is the group called?	Noble gases ✓
7) What does the symbol “He” stand for?	Helium ✓
8) What is the flame colour of Chlorine?	x
9) What does the symbol “B” stand for?	Boron ✓
10) What is the average temperature (°C) Argon burns at to create plasma?	x

Post-Test Questions	Answer
1) What does Boron do to the human body? (In-game effect)	x
2) What is the symbol for Sodium?	Na ✓
3) What is the average temperature (°C) Argon burns at to create plasma?	x
4) Neon is in a particular group of elements. What is the group called?	Noble gases ✓
5) What is the atomic number of Oxygen?	16 x
6) What is Sulphur known for? (In-game effect)	x
7) What does the symbol “B” stand for?	Boron ✓
8) Red Phosphorus is found in… (In-game effect)	x
9) What is the symbol for Magnesium?	Mg ✓
10) What is the flame colour of Chlorine?	yellow x
Would you play the game again? ("1" is the worst, "5" is the best, Honest answer)	5

11.10. Answers - Participant 22 (Non-Chemistry)

Pre-Test Questions	Answer
How would you rate your knowledge on the first 18 elements of the Periodic Table? ("1" is the worst, "5" is the best)	2
1) What is the atomic number of Hydrogen?	1 ✓
2) What is the symbol for Lithium?	2 x
3) What is the atomic number of Nitrogen?	3 x
4) What is the symbol for Sodium?	6 x
5) What is the atomic number of Carbon?	4 x
6) Neon is in a particular group of elements. What is the group called?	Halogens x
7) What does the symbol “He” stand for?	Helium ✓
8) What is the flame colour of Chlorine?	Halogens x
9) What does the symbol “B” stand for?	Boron ✓
10) What is the average temperature (°C) Argon burns at to create plasma?	1000000 x

Post-Test Questions	Answer
1) What does Boron do to the human body? (In-game effect)	Gets you buff ✓
2) What is the symbol for Sodium?	Na ✓
3) What is the average temperature (°C) Argon burns at to create plasma?	8000 ✓
4) Neon is in a particular group of elements. What is the group called?	Halogens x
5) What is the atomic number of Oxygen?	16 x
6) What is Sulphur known for? (In-game effect)	Smells like rotten eggs ✓
7) What does the symbol “B” stand for?	Boron ✓
8) Red Phosphorus is found in… (In-game effect)	x
9) What is the symbol for Magnesium?	Mg ✓
10) What is the flame colour of Chlorine?	Green ✓
Would you play the game again? ("1" is the worst, "5" is the best, Honest answer)	5

11.11. Answers - Participant 39 (Non-Chemistry)

Pre-Test Questions	Answer
How would you rate your knowledge on the first 18 elements of the Periodic Table? ("1" is the worst, "5" is the best)	2
1) What is the atomic number of Hydrogen?	1 ✓
2) What is the symbol for Lithium?	Li ✓
3) What is the atomic number of Nitrogen?	20 x
4) What is the symbol for Sodium?	Na ✓
5) What is the atomic number of Carbon?	5 x
6) Neon is in a particular group of elements. What is the group called?	Gases x
7) What does the symbol “He” stand for?	Helium ✓
8) What is the flame colour of Chlorine?	Green ✓
9) What does the symbol “B” stand for?	Boron ✓
10) What is the average temperature (°C) Argon burns at to create plasma?	400 x

Post-Test Questions	Answer
1) What does Boron do to the human body? (In-game effect)	Increase running speed ✓
2) What is the symbol for Sodium?	Na ✓
3) What is the average temperature (°C) Argon burns at to create plasma?	400 x
4) Neon is in a particular group of elements. What is the group called?	Noble gases ✓
5) What is the atomic number of Oxygen?	18 x
6) What is Sulphur known for? (In-game effect)	Fire x
7) What does the symbol “B” stand for?	Boron ✓
8) Red Phosphorus is found in… (In-game effect)	x
9) What is the symbol for Magnesium?	Mg ✓
10) What is the flame colour of Chlorine?	yellow x
Would you play the game again? ("1" is the worst, "5" is the best, Honest answer)	5