Design of Immersive VR Experiences for the Analysis of Gamification Techniques

D. W. Menadue, Dr. S. Lawes
Faculty of Engineering,
University of Nottingham, UK

ABSTRACT

This study aims to create a new perspective on gamification by starting with an entertaining game and making elements of it educational. This differs from the traditional definition of gamification, which is taking a learning experience and adding serious game elements to it. In this study, a fully immersive multiplayer virtual reality game was designed from scratch to teach players chemistry at a GCSE equivalent level. Specifically, the alkali metals were chosen due to their bright and colourful reactions, and how each of them reacts distinctly, but in an ordered and predictable fashion. For this study, objectives were split into two groups: design objectives for the game and research objectives for participant testing. The design objectives included creating complex systems such as: fracturing, dissolving, burning, boiling, and buoyancy scripts. The research objectives described the use of a twin survey approach to measure participant knowledge retention. The game was developed in an agile development workflow following the PDCA framework, creating discrete packages weekly. This meant there was always a working build in case of catastrophic failure. Creating the game took up 90% of the project time. This was due to the small budget, meaning all assets had to be designed by hand. The largest difficulty with the game design was the networking issues caused by the university's strict firewall policies. This caused the project to be largely delayed. In the end, all game design objectives were completed, and the project was prepared for testing. The project was then approved by the ethics committee and marketed. Finally, trials ran to determine how this gamification technique affects participant reactions, motivation, engagement, and learning. In total, 12 participants from a wide range of ages and backgrounds were tested. While individual participant results varied, overall, there was a 24% recorded increase in participant knowledge. This suggests that this study was successful, showing that games made for entertainment can teach real-life techniques and still be enjoyable.

Word count: 9998/10000 words

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1. INTRODUCTION

1.1 BACKGROUND TO THE PROJECT

Throughout history, students have often been taught through recitation, where a teacher of a class talks, and students listen and recite[1]. This method, known as teacher-centred education, was countered in the progressive education movement in the early 20th century. Education began to shift to a more student-centred approach, encouraging critical thinking and connection to real-world examples. Teachers would use practicals to demonstrate complex concepts that cannot be easily understood with words or diagrams[2]. However, this method breaks down when explaining concepts that cannot be seen and experienced in person, leading those who learn best by kinaesthetic methods to be unfairly disadvantaged. In the cognitive revolution of the 1960-70s, education shifted to an inquiry-based approach, emphasising problem solving, student collaboration, and "recognising students as active participants in their own learning"[1].

With the advent of computers, education again changed. Teachers were now able to create complex diagrams and models, as well as interactive displays for students to explore[1]. This massively improved the available teaching methods for complex topics, such as the structure of the atom. However, many of these tools are boring, potentially causing student engagement to plummet. This is where gamification comes in. Gamification, a field heavily rooted in psychology, is the altering of a serious task to be more game-like through the implementation of game culture aspects. For example, this could be the introduction of a reward system to give participants a dopamine boost on completing a task improving concentration for students with ADHD and autism[3]. The gamification of learning was frequently studied from 2012-14. However, it was found to be somewhat ineffective. It is key to note that many researchers separate games into multiple categories: games, serious games, and gamified experiences. Games are programs, such as Minecraft or Elden Ring, that people play in their free time to relax and have fun. Serious games are games designed for any purpose **other than entertainment**[4]. Gamification is the application of **serious game** elements to a non-game task. This means that a lot of gamification studies are not intended to be fun, enjoyable experiences and often do not include any 'play' activities. This project aims to break that definition by approaching the issue from the opposite direction: creating a game for entertainment and then 'learnifying' it with educational mechanics. Launders et al.[5] created a popular definition for gamification, providing four distinct constructs: "game elements (predictors), targeted organizational outcomes (criteria), intermediary individual changes (mediators), and personal and situational contexts (moderators)"[5]. In this study, the "criteria" are to teach chemistry and assess motivation-altering events. The success of the "criteria" is measured by comparing "moderators" and "mediators". Finally, the "predictors" were carefully designed to aid players' progress through the game. The project was conducted in VR multiplayer to further test if fully immersive gamified experiences can be an entertaining way to learn.

1.2 AIM AND OBJECTIVES

The aim of the project is to develop an immersive virtual environment to study the effectiveness of the gamification of learning in VR. Additionally, this study aims to answer the question "can non-serious games be used to teach?". Due to the complexity of this project, the objectives, and lots of other content, have been sectioned into two separate groups: the game, and the research. The game objectives refer specifically to the programmatical creation of the game, and content included within it. The research is defining the research protocol and methods of participant data acquisition.

At the very beginning of the project, it was decided that the game would be a chemistry classroom that teaches participants specific physics and interactions around the alkali metals. This was chosen because of the bright and colourful reactions of the alkali metals, which lend themselves to visual interactive demonstrations.

Additionally, the plan was to give players freedom to do as they please, enabling the assessment of distraction vs engagement. If participants pursue the 'educational route' they learn about common uses of the metals, and the colours that the metals burn. Should participants not engage with educational content, they would be able to break every object in the game, escape the lab onto the ceiling and explore the world outside.

Several motivation directors were planned for the game: an AI teacher; a voiceover that explains the concepts; a projected slideshow at the front of the class giving tips; and challenges for the players dispensing rewards on completion. Finally, informational posters were designed to give more in-depth facts about alkali metals and describing how to find distracting 'easter eggs' in game.

Game objectives

1. To create a simulation for the 4 functions: fracturing, dissolving, burning and exploding.
2. Conditionally according to time constraints, create and implement boiling functions.
3. To implement methods of teaching in VR such as informatic posters and voiced teaching.
4. Conditionally according to time constraints, implement awards systems and interactable NPC teaching.
5. To implement 3 taught chemical/physical interactions.
6. To implement between 5-10 materials that can be used in interactions.

Research objectives

1. To create pre- and post-simulation Microsoft form surveys optimised for quick accurate data acquisition using 15 or fewer questions.
2. To measure user satisfaction and immediate retention of taught knowledge through the pre- and post-simulation surveys.
3. To measure user engagement and enjoyment via mid-simulation data-logging of candidate reactions and motion sickness events.
4. To collate survey and recorded data and investigate correlations between in-game events and participant response.

2. LITERATURE REVIEW AND PROJECT INSPIRATIONS

Defining The Research.

In 2022 Sridevi Nair et al.[4] published a systematic review of studies on gamified learning. This review looked at 64 different studies from around the world targeting different age groups, and dependant variables. The review found that 47 of these studies were statistically significant. These variables can be used as a starting point to define the best research objectives for this study.

Table 1: Nair et al.[4] **table of classified independent variables**

variable	No.
Attitude change	5
Behavioural change	8
Learner engagement	15
Learning	36
Motivation	15
Perception	10
Reaction	6

A 2024 study of 177 students by Klingenburg et al.[6] found that VR immersive simulations improved student presence, agency and embodied learning. However, the students showed no improvement in transfer of skills to the real world when compared to students who ran the simulation through a computer screen. This suggests that despite the immersive benefits of VR, it does not affect user confidence in the real world. Because of this it would be ineffective to test for a change in attitude or behaviour of the participants. Alongside this, to simplify data collection, and to make participation easier to organize, this study will only be run once per group. This lack of repeat testing means it is not possible to measure the long-term knowledge retention of participants.

However, it would be possible to evaluate the remaining variables: learner engagement, (short-term) learning, motivation, perception, and reaction. To further narrow down the scope of research, these variables are defined and explained below:

Learner engagement is often considered to be a persisting issue for students and teachers. To be disengaged does not indicate low achievement in students but is rather an indication of a lack of excitement toward a subject, leading to a lack of commitment, or dislocation from the task leading to disruption in the classroom. "In contrast engaged students make a psychological investment in learning"[7]. The challenge with engagement is to balance student boredom with the taught goals.

Learning, in the case of this study, is classified as the immediate retention of knowledge gathered by participants direct involvement in the game. It is the easiest outcome to test, and as such is the most assessed variable. This study will test participant learning as a baseline to judge the general success of the project, and to validate the results given by the more complex independent variables. Learning is typically measured by the assessment of learning outcomes. This "evaluation is conducted to answer either of two questions: whether training objectives were achieved (learning issues), and whether accomplishment of those objectives results in enhance performance on the job (transfer issues)"[8]. Due to the cost and danger to participants that would arise from testing the skill transfer, this study will only aim to assess learning issues based on the success of learning outcomes.

Learner motivation "is the force that influences enthusiasm about the [training] program"[9]. To measure motivation, this study will compare the time spent engaging with educational content and the time spent distracted. Motivation is a simple variable to assess, but a difficult variable to justify outcomes for. For example, if a participant joins the research group with specific intent to mess up study data, the motivation of the participant will be high, but knowledge retention and other variables would be outlying. That said, the key principles of creating motivation are important to this study to ensure that participants will engage with the taught content.

Noe R et al.[9], explains that motivation requires "a stimulus that directs participants to learn". This is called a director. Additionally, to ensure consistent motivation there must be "a force that influences the use of newly acquired knowledge and skills" – this is known as maintenance.

In this study, the director will be the Challenge-Reward system, which give challenges which are designed to encourage participants to play and experience reactions. Maintenance will be difficult to artificially enforce as the taught concepts of the game are abstract and not regularly used in the real world. However, this can be aided with a reward system, utilising positive reinforcement to encourage learners when they achieve learning objectives. This method can also be used to improve concentration of participants with ADHD or autism[3].

Perception is a measure of how a user's predisposition towards gamification as a technique effects their interaction with the study. This is studied mainly due to the negative representation that gamification had in the early 2010's. While this is an important variable when teaching serious important information like staff training programs, it is irrelevant for the more light-hearted content this study is aiming to teach.

Reactions are "post-training opinions regarding the training program"[4], this can be emotional responses such as enjoyment, satisfaction, disappointment or even motion sickness. Reactions also include participants perception of how useful the selected method of training is, and how much effort they believe is required to perform well in the required training. Warr and Bunce [10], classify these post-training reactions as: reported enjoyment, usefulness, and difficulty. Warr and Bunce explain that participant enjoyment, while key to participant motivation, has no theoretical association with learning achievement. However, perceived usefulness is paramount to learning and altering participant behaviour. Perceived difficulty of the training is labelled as the only reaction that can predict immediate learning. This study will aim to keep the perceived difficulty at a minimum, to enable the effective measurement of other variables. Unfortunately, the chosen taught content will have very little influence on participant lifestyle so the perceived usefulness of the project will likely be small, potentially leading to disengagement. The study will aim to fill this void with 'play' activities increasing users' enjoyment and thus general motivation.

This study tests the learner engagement, motivation and reaction of the participants, using short term learnt information as a validation method. To verify learners' ability, a set of learning objectives have been created.

Learning objectives for participants

LO1. To learn to control the VR system
LO2. To learn the names and order of the alkali metals
LO3. To learn the reactivity order of the alkali metals
LO4. To learn the colours each metal burns

The Game.

To create and engaging experience, inspiration has been taken from other popular games.

Waltz of the Wizard by Aldin Dynamics [11] is an interactive VR alchemy game, where the user is placed in a wizard's tower with a *friendly* skull, who acts as an NPC (non-player character) guide to talk you through your experience. There is no specific goal in this game, the player is just placed in the room with things to interact with, that when combined, have interesting properties and can teach you magic. Upon acquiring all possible magic from your experiments, there is a rudimentary dungeon crawling segment that allows you to use your new-found knowledge. Despite the simplicity of the game, the experience is incredibly engaging and fun specifically due to the chaos that can be created and how sarcastic the skull NPC is. This project takes inspiration from this concept, with similar mechanics and objectives, but making them representative of the real world. Instead of a wizards tower the users are placed in a classroom, instead of magic the users learn science. To keep the engagement that waltz of the wizards has whilst being educational, scientific interactions must be visually pleasing and enjoyable. As distraction from this, the game aims to have every object being interactable and destructible, meaning any large explosion could destroy everything including the walls and ceiling tiles.

As the game is created mainly to test user engagement, another necessary aspect the game is some sense of distraction. An entertaining way of doing this is with a subtle sense of evil. The chosen inspiration for this is the portal games by Valve [12]. This is a game series where the player is a test subject in a lab, called Aperture Laboratories, controlled by an evil robot who is pretending to be good. This project is run with similar conditions, where the player is a test subject for the evil fictional Lycorp Laboratories. Much like Portals famous 'Ratman' rooms, this game contains easter eggs that the player can find. Giving the player reason to explore and find the game's secrets. Implementing this along with other world building techniques has been shown to increase engagement in gamified environments. Sailer et al.[13], in a comprehensive meta-analysis, states that "when considering interventions focusing on behavioural learning outcomes, including game fiction is promising; for example, introducing a fictional game world, which is relevant throughout the gamified intervention, […] can help to foster learners' skills".

Finally, both Blender[14], the Roblox game engine[15], and the unity game engine[16] were researched extensively to determine the best method of creating this project. It was determined that unity, despite its increased complexity, was the best game-engine for this project. This is because, Roblox graphics while editable, aren't sophisticated enough to support good liquids or make the game feel immersive. Blender was determined to be the best tool for asset creation due to its massive flexibility and the speed it can create objects, textures and animations.

3. GAME CREATION METHODOLOGY

The game was programmed iteratively in an agile development style by creating a fully functional work-package every week – this means, if the most recent package failed, the project can be reverted to a previous form. Each work-package was completed following the Plan-Do-Check-Act framework allowing constant flexibility and ensuring the best possible outcome.
The work packages for the game are as follows:

1. Creation of unity multiplayer VR environment.
2. Design and concept generation for classroom /world layout.
3. Creation in blender and implementation of custom assets in unity.
4. Creation of fractured models in blender.
5. Implementation of fractured models and 'Fracturable' function into unity.
6. Implementation of explosion function in unity.
7. Implementation of 'dissolvable' function.
8. Implementation of sound effects.
9. Implementation of recycle & cleaning (r&c) droid systems.
10. Implementation of fire animations and burning function.
11. Implementation of boiling animations and function.
12. Rework of Networked multiplayer systems. (added due to necessity later in the project)
13. Creation and implementation of teaching resources and (subject to time constraints) an NPC teacher.
14. Implementation of system alerts and pop ups for achievements. (subject to time constraints)

3.1 DESIGN PROCESS: THE GAME

The game was created following the work package order laid out above.

Work package 1, to implement multiplayer VR, was simpler to set up than expected as unity has a free sample scene that sets this up for you. However, this system was not completely functional due to the university's strict firewall policies causing it to break on university property. This problem was never fixed by the university IT staff and meant an additional Network fix package (12) had to be appended to the project.

Packages 2 & 3 included complete asset modelling, texturing and then exporting from blender to unity as an '.FBX' file. This took far more attempts than expected, due to unity's 'back face culling' causing models to render inside out unless properly normalised. After asset creation the layout of the classroom was chosen and the assets imported into unity.

Figure 2: Blender render of fractured and normal glassware

VR graphics are by design much lower quality than what is possible in blender. This meant the glass texture had to be specifically re-designed for the UnityRenderPipeline (URP).

Of all game objectives and work packages, only the teacher AI was not completed.

In total, the completed game had over 29 blender files, 41 FBX models, 92 game object prefabs and over 40 C# scripts. All of this combined to over 3400 fully customised objects.

Additionally, 42 sound effects were sourced from the free pixabay audio library[17] and 8 sound effects were created by hand using Bandlab free audio editing software[18].

3.2 SPECIFIC FUNCTIONS

The most complex C# scripts and functions have been highlighted and explained in detail below.

3.2.1 PHYSICS INTERACTION SETUP SCRIPT

The physics interaction setup was the most complex function and the main material data storage system. Every object in the game must be given this script so other functions can access the 22 material properties and functions it stores. These properties include:

Material name, material image (for storing the atomic structure), density, if the material is burnable, what temperature it burns at, the 'type' of fire it burns with, the temperature it ignites at, the scale factor of fires, the colour of fire it burns with, the maximum number of fire emitters, the speed fire spreads, melting temperature, boiling temperature, thermal resistance, whether the material dissolves in water, whether it creates bubbles in water, or ignites in water, how much force it produces when it burns in water, and the delay to spontaneous ignition in water.

This script also handles burning, boiling and resetting objects after fracture.

Temperature is controlled in this simulation through a 'temperature target' system. Normally, an object is at 23^{o}c. However, when it goes through a fire's collider, its temperature target is set to 300^{o}c. The temperature of the object then increases at a rate following the equation:

$$temp \mathrel{+}= \frac{TempTarget - currentTemp}{Thermal\ resistance} \tag{1}$$

This makes the temperature gradually change between set temp and current temp.

If the object is then removed from the flame, the temperature target is gradually decreased back to 23^{o}c. While this is not specifically accurate to real life, this is a non-processor-intensive method to get a realistic *feel* to temperature change.

Should an objects temperature target be higher than its melting point then the temperature target is instead set to its melting point.

Should an objects current temperature exceed its ignition temperature, a fire particle emitter is spawned onto the surface of the object where the heat was last applied. To find this point, a vector is raycast (drawn) from the location of the original heat source straight through the objects volume, where this ray collides with the object first is its closest point. Once the fire has been spawned it slowly moves towards the centre of the object giving the impression of fire spreading. Additional fire emitters are spawned at a rate of one per 'FireSpreadtime' game frames.

Once the object is on fire its temperature is permanently set to 300°c and can only be altered by submerging it in water which forcibly sets its temperature target to 13°c and destroys fire emitters.
Note, this does not work for materials that burn in water.

If an object is burnt for too long, it is destroyed. If the burning object is 'fracturable' then the 'BreakTheThing' function from the Fracturable script is called.

Finally, this script also houses a set of functions for creating and destroying objects in multiplayer over the network.

3.2.2 CHANGE FIRE COLOUR ON COLISSION

This script was required to help participants complete LO4. This is one of the shortest scripts in the game but, it took an incredible amount of time to develop. In the real world, when you hold certain metals over flames, the fire that touches the metal changes colour. Performing this in unity was difficult as unity has no method of altering individual particle appearance after it has been created. To get around this, every fire must have a 'secret' smaller fire hidden inside it. When an object hovers over the large flame the secret sub fire reads that object's 'PhysicsInteractionSetup' script for its 'fireColour'. Then, whenever a particle from the original fire touches this object it is killed instantly and replaced by a single particle from the coloured sub fire emitter. This method makes it seem like the fire collides with the object and changes colour as it wraps around it.

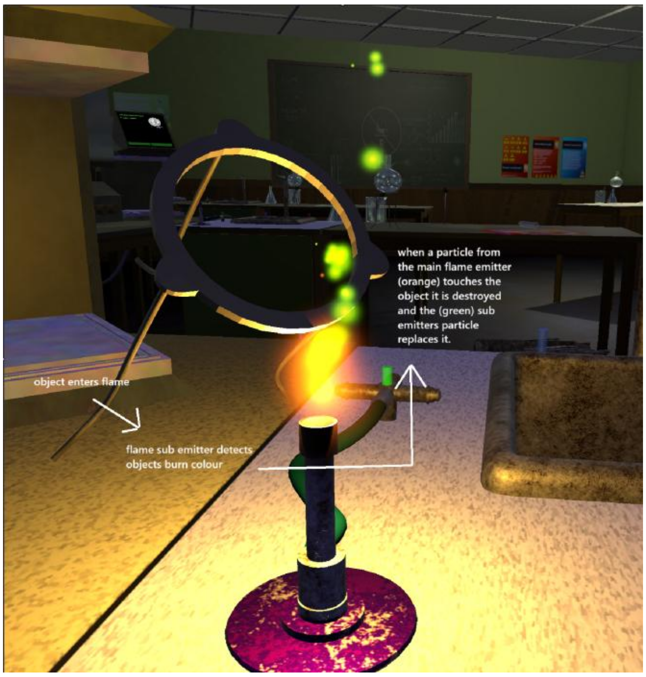

Figure 2: An image depicting of fire colour change systems

3.2.3 FRACTURABLE SCRIPT

The fracturable script takes the relative collision speed of two objects and calculates the kinetic energy of the impact to determine if an object has fractured. On fracture, a function 'BreakTheThing' is called. This function deletes the original model removing it from the classroom. The function then spawns the 'fractured' version of the object in as its replacement.

Once the recycling and cleaning (r&c) droids were implemented, 4 more linked scripts were added that drastically effected the way the fracturable function performed. The most important change was the implementation of a 'recycling' system, this meant, upon the smashing of an object, the object is immediately disabled but not deleted, making it vanish out of the world to be replaced with its fractured model. The original object is then appended to a 'recyclingList', and the fractured object is then added to a 'cleanUpList'. The r&c droids are constantly scanning their respective list for new objects, determining which object is the closest to their current location and then moving towards it. Upon reaching their target location, the cleaning droid deletes the fractured models and the recycling droid teleports the original object's model back into the game. This method is graphically explained in the figure below, starting with the falling conical flask:

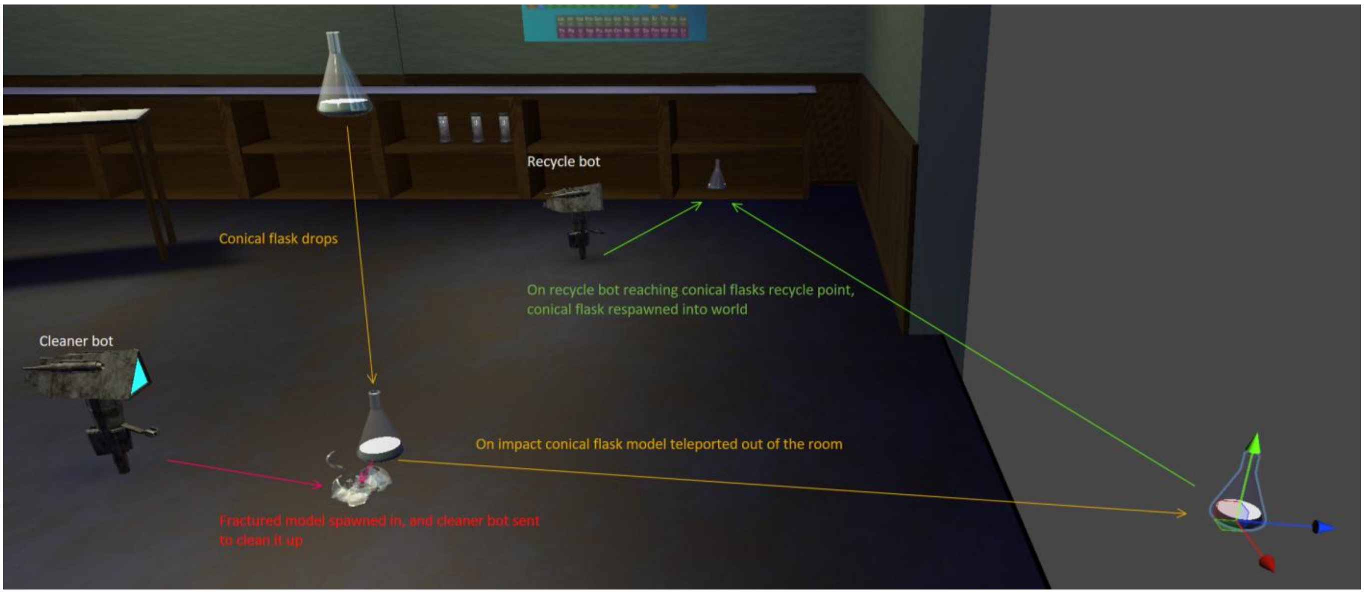

Figure 3: Graphical representation of object pooling r&c system.

This recycling method is called object pooling and is used in several forms in many different functions, including creating and destroying bubbles, or emitting sparks on burning metals. This method, while more complex than instantiation or repeatedly deleting and respawning objects, is significantly less performance intensive.

3.2.4 WATER SYSTEMS

This system was required to help participants complete LO3.

There is no default method of creating water or other liquids in unity. This means that, everything must be done by hand. Two separate textures for water were created: water in a flask, and water in the sink.

Flask Water texture

Water in a flask was created by duplicating the inside faces of the glass bottle and scaling it down by a tiny amount. This became the 'liquid' object. Then, the bottom 50% of the liquid objects mesh was rendered. This caused the mesh to be rendered based on the object's orientation relative to the world, which makes the glass look like it is 50% full of liquid. For this effect to work unfortunately the liquid has to be opaque to avoid texture clipping, and the back face of the liquid must be slightly emissive or 'glow in the dark'.

To improve the effect, a wobble script was added that simulates inertia by creating a delay to how the liquids cut face moves. This wobble script also handled the filling and emptying of the glasses by changing how much of the liquid mesh is rendered.

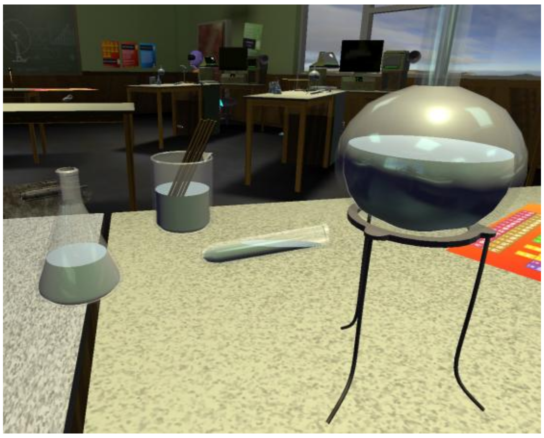

Figure 4: The water texture used in flasks

This texture was designed following 'Lone Developers' explanation [19]

Sink water texture

The sink water was easier to create and make look more realistic. It used a flat almost transparent plain with a sinusoidal noise pattern scrolling across it. This noise shifted node displacements giving the impression of subtle waves across the material surface. Additionally, this texture used a 'depth write' method to tell how far below it a submerged object was. Then the part of the mesh that the player can see covering the object would change its transparency depending on how deep under water the object is. By using this method, the single flat plain simulates ripples and volumetric lighting. On top of this, objects close to the surface cause the water to turn white, making it seem like there is foam or subtle breaking to the water's surface where it touches things. If an object is floating in the water, a particle emitter gradually releases ripple ring particles that slowly expand to further the impression of an object breaking the surface of the water. Finally, to top off the effect, the 'refraction' of the liquid is changed based on the height of the node. This gives the impression that reflections of the water swirl and shift as it ripples.

The final texture for this can be seen below in figure 4.

This texture was designed loosely following the official unity YouTube channels tropical ocean water shader tutorial.[20]

Buoyancy system

Underneath the flat planar texture of the sink water, is an invisible triggerable box collider. This collider is responsible for handling everything that goes on in the sink. When an object enters the sink it is added to a 'floaters' list. The floaters are then set to having a higher linear and angular drag than they would in air, and a buoyancy force is applied to them.

Calculating buoyancy force is done in 3 stages, firstly, calculating volume. In unity there is no method to determine the volume of an object. To counter this, every material has its density stored in its physics interaction setup and its mass stored in its rigid body settings. Using this mass and density allows the calculation of total volume. The second step is to calculate the amount of object submerged. The only useful information unity gives for this is the objects 'renderer bounds'. This is a set of two coordinates that define opposing corners of a cuboid the object would completely fit in. Calculating the vertical displacement between these coordinates, allows the amount of the object below the water plane to be found. This is then multiplied by the previously calculated volume to get a more accurate number.

The third step is to calculate and apply the force. The equations used for this were:

$$BoyancyForce = 9.81f*waterDensity*mass/density; \quad (2)$$
$$force\ applied = BoyancyForce*volumeSubmerged*0.6 \quad (3)$$

The scalar of 0.6 is used as the volume from the renderer bounds always overestimates volume submerged.

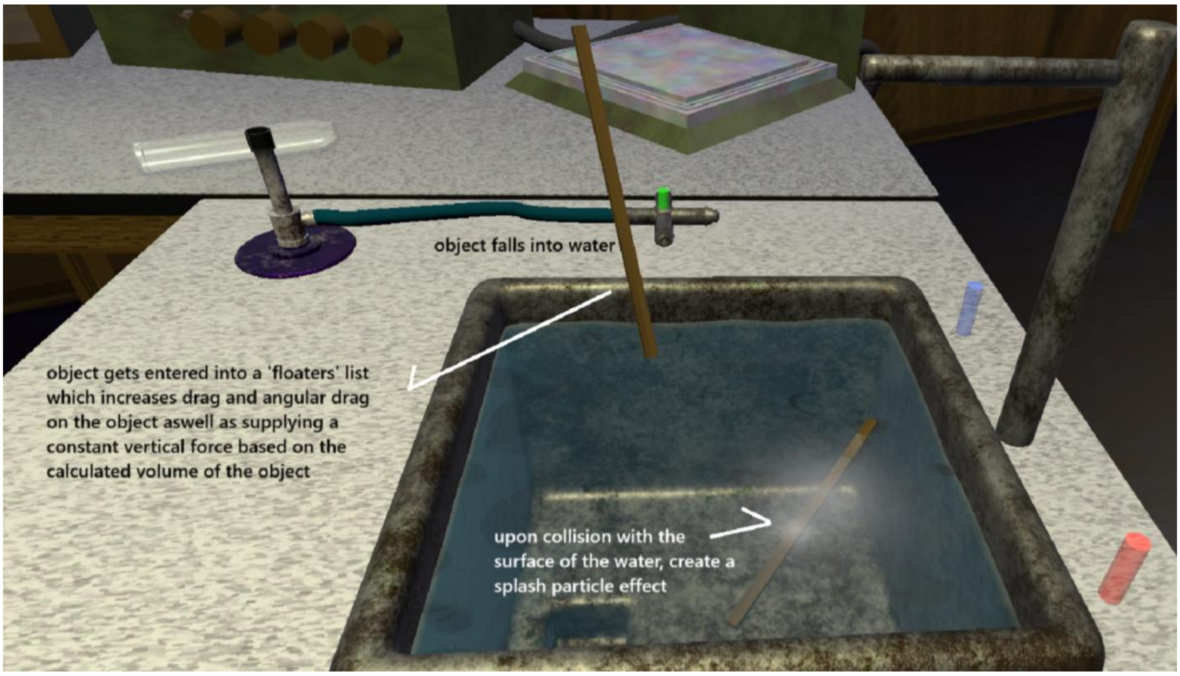

Figure 5: The water texture used in Sink and explained buoyancy system

Once all of this has been calculated, a set of simpler special interaction functions run that determine what happens to the object. These include: calling the physics interaction setup for the object to set it on fire or explode it if it is a reactive material; using object pooling to spawn bubbles under the object to simulate hydrogen being produced; and dissolving materials until they fracture.

3.3 CHALLENGE-REWARD SYSTEM DESIGN

To design the predictors for the game, criteria and moderators must be considered. It was determined that the Challenge-Reward System the best method of achieving project targets whilst being accessible for all players. This system was designed as a motivation director to inspire users into interacting with the educational aspects of the game. To do this, 3 devices were added to the worktables: a computer screen to display challenges; a material identifier allowing users to find specific information about items in the game; and a dispensary, to dispense rewards on completion of challenges.

Figure 6: The dispensary, computer screen, and material identifier

The challenges used in this system were carefully designed to produce distinct results from participants.

Challenge 1: Introductions

This challenge was designed to introduce the user to the game and get them used to the mechanics and controls (LO1). It required users to:

1. Turn on the tap and fill the sink with water.
2. Fill the conical flask with water.
3. Turn on the Bunsen burner.
4. Using the Bunsen boil the water in the conical flask.
5. Use the material identifier to find the difference between the conical and boiling flask.

Tasks 1-3 got the user used to interacting with the environment grabbing objects, pressing buttons and introducing them to what is available in the game.

Successfully completing task 4 causes the conical flask to smash as conical flasks are often not heat resistant. This shows players that in this game, things can be broken, and how to replace them.

Task 5 teaches players how to use the material identifier to get information about different materials.

Once completing this task players are rewarded with a toy xylophone.

Challenge 2: Does it Bubble?

This challenge was designed to forcefully teach players information about interactions of the metals (LO2 & LO3);. It took the form of a multiple choice quiz where getting an answer incorrect would immediately reset you to the beginning and shuffle the order of the questions. This was done, alongside an annoying incorrect buzzer to make it frustrating to brute force the questions. There were 8 questions in total. 6 of which were educational, and 2 of which were for entertainment.

Table 2: a table of questions used in Challenge 2

question	Reason for asking
How many legs does a standard table have?	This question always appeared first, allowing players to clearly see they had been reset to the beginning after the buzzer.
Which of the below alkali metals are most reactive?	This prompts users to test elements or read the periodic tables.
Which of the below is the common name for sodium hydroxide?	This questions answer was only found on its 'atoms are cool' poster on the wall of the classroom, and in a voice over by the teacher.
Which of the below gasses are created when an alkali metal reacts with water?	To answer this question players had to read the posters on the wall.
How did you get into the classroom?	This is to inspire players to explore the room and check the door, as a purposeful distraction
Which of the below are too dense to float on water?	This prompts users to put alkali metals in water.
What is the density of caesium?	This prompts users to use the material identifier.
Which of these elements has a delay before spontaneously igniting on water?	This prompts users to put alkali metals in water, showing the increasing reactivity of those elements. This question has incredibly similar answers to both the 'too dense to float' and 'most reactive' questions, but all have different answers. Making brute forcing even more difficult.

Watching participants complete this challenge is the key insight into how participant moderators effect mediators, when interacting with game elements.

The reward for completing this was a bubble gun which when ignited fired purple burning bubbles.

Challenge 3: Into the Fire

This challenge inspires players to complete LO4; by burning every object in the game, trying to find something that burns every colour of the rainbow.

All colours except green and orange were alkali metals. Green fire was produced by burning the copper boiling flask stand. Completing this challenge meant participants had to fully understand the game system and explore the games limits thoroughly.

The Reward for completing this challenge was a rainbow flamethrower.

Challenge x: The secret challenge

This challenge was only available to people who scrolled through the whole list of challenges twice. It instructed people to escape the facility. This was created as a purposeful distraction. The reward for completing this was pure francium.

3.4 NETWORK ISSUES

Over the course of this project there was constant communication with the university IT administrators. Initially, this project was created using Unity's multiplayer 2022.3.48f1 multiplayer VR template. This template was initialised in the very first work package of the project and worked flawlessly in home testing. Unfortunately, when tested on university campus, it broke. This issue was not fully understood for ~6 months. As such, multiplayer testing remained impossible for a large portion of the project. The issue was later discovered to be caused by unity multiplayer running via a server system attached to unity cloud. This meant connections from inside the university required ports to be opened for a live server in a different country. This issue was not possible to fix for the university staff as it was not a 'on campus' firewall issue, rather an issue with the overarching 'eduroam' network disallowing this type of multiplayer gaming. This problem was eventually fixed by manually rewriting the unity networking scripts. This was done following unity discussion user italovs example, taking their GitHub[21] files and combining the relevant project work. This fix fundamentally altered Unity's networking software by 'spoofing' the international server on a local device. This effectively tricks the game into thinking it is connecting to an international server when it is never leaving the local network. This enabled LAN multiplayer which finally worked on university campus.

Once multiplayer testing was possible, a massive amount of the project had to be rewritten as it was not appropriately optimised for multiplayer. The main error was caused by 'RPC' tags.

RPC, or Remote Process Calls, determine which of the connected computers should be running what functions. If the wrong computer is running a command, then either: that computer fails that function call causing the multiplayer to become de-synced; or the function succeeds when it is not supposed to, making all other computers suddenly delete an object they shouldn't. A specific kink to Networking is only the server can 'spawn' or 'despawn' objects. This means; to spawn an object, client computers must request it via an RPC from the server. Finally, every object in the game is 'owned' by the server, unless it is picked up by a client in which case ownership is transferred.

As an example of the increased complexity, the full Fracturable function from 3.2 has been re-explained in the appendix, showing the correct uses of the RPC tags.

4. TESTING METHODOLOGY

This study evaluates participant motivation and engagement by measuring how much time participants engage with educational content when there are so many game-element based distractions. The chosen method of examining was via 2 surveys, pre- and post-simulation, alongside direct observation or participant reactions and emotions.

The steps to designing the tests were as follows, survey design, ethics review, marketing, testing and results analysis.

4.1 SURVEY DESIGN

The surveys were created in Microsoft forms following the design tips from Parsons [22]; with questions mainly consisting of multiple choice and 'rate on a scale' questions. The survey was created to take Less than 5 minutes to complete, with minimal reading comprehension required. This makes data analysis from the forms easy, enabling participants to be grouped and their experiences quantified.

Pre-simulation survey

The pre-simulation survey aims to document baseline knowledge of VR and asks some probing questions about alkali metals.

Table 3: A table of pre-simulation questions

Question	Reason for asking
Have you used VR before?	Determining if VR competency effects results.
How regularly do you play video/computer games?	Determining if gaming competency effects results.
How regularly do you experience motion sickness?	VR is known to cause Motion sickness.
Do you agree to your data being collected?	Ethics and data handling consent.
Are you aware of the possible health and safety risks during this trial?	Ethics; health and Safety consent.
Do you agree to participate in this study?	Proof of participant consent.
Which column of the periodic table are the alkali metals?	To probe people into looking at periodic tables. (LO2)
Which of the below is an alkali metal?	To probe people into looking for these elements. (LO2)
What colour does lithium burn?	To probe people into burning items in game. (LO4)
Which of the below gasses are released when an alkali metal reacts with water?	To make participants aware of this reaction. This question also appears in Challenge 2. (LO3)
Rank the Alkali metals from least to most reactive?	To make participants aware that reactivity changes. (LO3)

The latter half of the questions were asked both to gauge knowledge of the taught content, and to get participants thinking about the alkali metals. This also enables the post-simulation survey to test participant improvement on these specific questions.

Post-simulation survey

The post-simulation survey is used to record participants progress through the learning objectives. The survey measures user improvement in knowledge through comparison to pre-simulation survey answers. The post-simulation survey also questions users' enjoyment, perceived usefulness, and perceived difficulty (reported reactions). By using both surveys in conjunction the efficacy of the experience can be discovered.

Table 4: Post-simulation Feedback questions

question	Reason for asking
Was the experience enjoyable?	To determine the success of the study.
Was the experience fun?	" These were all rate on a scale of 0-5 questions.
was the experience educational?	"
Would you want to play the experience again?	"
Does the experience require more content?	"
Did the multiplayer aspect improve the experience?	"
What were your overall thoughts on the experience, did you enjoy the game, and were there any improvements you could recommend?	An open answer question for general feedback.

Table 5: Questions gauging progress through the game

Question (Did you…)
complete Challenge 1?
complete Challenge 2?
complete Challenge 3?
complete secret Challenge 4?
escape through the ceiling?
read one of the information leaflets?
manage to break a wall or window?
find a major glitch that broke the simulation?

Next the survey re-asks the pre-simulation alkali metal questions to test participant improvement.

Finally, the survey asked new more complex questions.

Table 6: New Alkali metal questions

Question	Reasoning
What colour does caesium burn?	To check if players remember learnt information from engaging with Challenge 3. (LO4)
What is the common name for sodium hydroxide?	To check if players recall information from Challenge 2.
What is the half-life of francium?	To check if players engaged with informational posters.

Alongside the surveys, direct observation was used to log interesting events. This assessment of learning issues gives insight to the effectiveness of the experience. The protocol for observation was to log the timing of certain events. For example, 'Participant A, motion sickness break: 11:15-18'. Other events that were logged were direct quotes from significant reactions, events that caused excitement, events that caused frustration, and events that caused distraction. This was done both in session and by reviewing session recordings.

4.2 ETHICS REVIEW

Ethics review was submitted on the 24th of February and accepted on the 31st of March. Initially, this study had been planned to run on the 24th of March, on the last week before the Easter break. This led to further delays causing the actual study to be run the first week after the Easter break (28th April) This led to fewer applications than expected due to the availability of potential participants decreasing as exam season approached. Ethics confirmation can be seen in the appendix. Further ethics documentation can be supplied upon request, or viewed in the project OneNote, linked in the appendix:

In the Ethics Reviewer Decision, it was mentioned that there was no action plan for participants with epilepsy. The created action plan led to the addition of a 'do you have epilepsy or similar sensitivity to bright lights?' question to the sign up form and pre-simulation survey. Additionally, those with epilepsy were to be contacted before the session and supervised appropriately. In the end, only one candidate with epilepsy signed up to the simulation, they were appropriately advised and had no issues during the session.

4.3 MARKETING

Marketing was done through a variety of techniques: walk in traffic; messaging UoN group chat's; and posters on UoN billboards.

The initial poster design followed the themes of the game and were 'dystopian'. This poster was used on pinboards and left as leaflets around campus. After review with VR technician Christopher Brooker this initial poster was deemed too different from other University standard posters to be used on the TV-poster boards, so a revised version was created.

Both posters can be found in the appendix.

The project was marketed to people of all age groups and backgrounds, aiming to get a diverse audience of participants.

4.4 TESTING

On the day of the participant tests. Participants were first handed the pre-simulation survey. They were then given a debriefing on potential hazards including motion sickness, loud noises and sudden bright lights.

They were then seated and placed into the simulation and given a 5-10 minute personalised introduction to VR. This explained the controls, how to personalise settings and fit the headbands. They then started the simulation. During their play through, their views of the VR world were recorded to review later and their emotional responses monitored by the researcher.

After their session, the players were given the post-simulation survey and debriefed with an informal exit interview.

After testing, participant results were assigned serial numbers, and names and other identifying information removed from the records.

5. DISCUSSION OF RESULTS

The study collected the results of 12 participants in 5 multiplayer sessions.

5.1 REACTIONS

Reaction was measured by direct observation alongside results from the post-simulation survey. The following questions were asked as a 'rate how much you agree' question. Results from this question were assigned points: agree was worth 5 points, neutral was worth 3, and disagree was worth 1.

Table 7: a table of reaction results from the post-simulation survey

Question	Mean score	Standard deviation
The experience was enjoyable?	4.85	0.36
The experience was fun?	4.92	0.27
The experience was educational?	4.39	0.63
Would you want to play again?	4.08	0.83
The experience requires more content?	2.77	1.48
Multiplayer improved the experience?	3.85	1.10

This data shows a largely positive reaction to the experience, highlighting that people definitively thought it was fun, and enjoyable, and 88% of people believed the game to be educational. The most 'controversial' results, as shown by the high standard deviation, were whether the experience requires more content, and if multiplayer improved it.

In the exit interview, 5 players mentioned that the multiplayer aspect of the game made the game more fun and easier to understand. However, it also made it harder to concentrate and complete challenges. This suggests that in this game environment, multiplayer interaction enabled players to learn from each other, but the direct interaction was a distraction. This agrees with the main findings from a December 2024 meta-analysis by Hatta N. et al.[23], which found multiplayer in educational games to be beneficial to critical thinking. The distractions caused by multiplayer in this study could be removed by making players work together more directly, so instead of being distracted by another's actions, players are working together to solve a task.

During the tests, 4 of the participants had to pause due to motion sickness, and 2 of these had to stop fully. Other participants mentioned that the motion sickness was worse than they expected but they only noticed the motion sickness after removing the headset. The opinion was expressed that the simulation would be best performed standing, in a room where participants would be able to walk around freely, rather than relying on the game's motion systems.

Throughout the game, participants were regularly laughing, expressing enjoyment, and demonstrating curiosity. One exception to this was in attempting to complete Challenge 2. Those who attempted to brute force the task were met with repetitive, obnoxious buzzers. Two players even displayed clear signs of frustration. This shows that the players were motivated enough by the challenges to become engaged and develop a degree of emotional commitment to the game.

5.2 LEARNER ENGAGEMENT AND MOTIVATION

Learner engagement was measured by comparing the time users spent engaging with educational content to time spent exploring or otherwise distracted.

For most of the test sessions, during the first 10-15 minutes, participants tended to be exceptionally engaged, with everyone following the challenges on-screen. The only major exception to this was if the room ran out of a necessary item, which caused some players to resort to theft, and subsequently confused searching. This issue did not exist in single player tests.

Although engagement could have dropped as soon as people received their rewards, most participants chose to interact with them for less than two minutes before moving on.

Engagement remained high as participants tackled Challenge 2, exploring more of the room, but still few actively being distracted.

The majority of participants started to become distracted after completing Challenge 2, in most cases once they had used caesium to create a big fire.

During their test sessions, 84% of participants completed Challenge 1, completing LO1; 76% completed Challenge 2, completing LO2 & LO3; and 38% completed Challenge 3, completing LO4. This curve was caused by people running out of time, due to distraction or having difficulties controlling their characters.

Every player who completed Challenge 3 was encouraged to explore and break the world, this was indicated by secret Challenge 4 (escape).

Of all participants, only 2 managed to escape the facility onto the roof unprompted, and discover the major easter egg of the game, and be rewarded with francium. Other players often followed suit after one member of the play session discovered this secret.

The speed at which participants completed these challenges was clearly related to 3 factors: VR competency, gaming efficacy, and player assumptions into the game's rules (moderators).

Both players that never completed Challenge 1 were first time gamers, who had never used VR. This led them to have little control over their character causing them to struggle in game and fail LO1.

Other players assumed that information was not available, and Challenge 2 answers had to be guessed. One participant said, in relation to the posters, that "there is an assumption that set dressing is just set dressing". This psychological assignment of these rules that may not exist, often called the magic circle[24], caused many players to ignore elements of the game they expected not to be relevant to their task. This meant players were slow at completing challenges until they had broken their expectations and acknowledged the actual rules of the game. Those with high VR competency and gaming efficacy accepted the rules of the game the fastest.

At no point in the study did a participant remove their headset because of a real world distraction such as texting.

5.3 RETENTION OF TAUGHT INFORMATION

Player knowledge retention was measured through alkali metal questions in both the pre- and post- simulation surveys.

To get an accurate measure of how much people learnt, the probed questions that appeared in both simulations were marked, 2 points for a correct answer, 1 point for a correct answer with uncertainty (2 answers selected), 0 points for an incorrect answer.

Table 8: a table of average score per question, per simulation

Question	Average score		Improvement in score [% of max possible score]
	Pre-simulation	Post-simulation	
Which column of the periodic table are the alkali metals?	0.83	1.308	0.475 [23.8%]
Which one of the below is an Alkali metal?	0.00	1.000	1 [50%]
What colour does Lithium burn?	0.17	0.62	0.448 [22.4%]
Which of the below gasses are released when Alkali metals react with water?	1.33	1.54	0.205 [10.25%]
Rank the Alkali metals in terms of reactivity, from least to most reactive.	1.15	1.44	0.291 [14.55%]
Average total score:	3.49	5.91	2.419 [24.19%]

The final 'Rank the…' question was more difficult to assign a point value to. This was made more complex as 6 of 12 players misread the question and ranked elements from most reactive to least reactive. To score this, players were given the benefit of the doubt and inverted lists corrected. Then, the number of incorrect elements were counted, along with the number of 'steps' each incorrect element would take to correct. These two numbers were then averaged and subtracted from 6, the number of total elements. This gives a score from 0-6 points per answer. To get a point score relative to the other question in the quiz this result was scaled by 2/6.

This led to the equation:

$$\boldsymbol{point\ value} = \left(\boldsymbol{6} - \frac{\boldsymbol{Incorrect\ elements + No.\ wrong\ moves}}{\boldsymbol{2}}\right) * \frac{\boldsymbol{2}}{\boldsymbol{6}} \quad \textbf{(4)}$$

These results show an average score increase of 24. The questions with the lowest improvement were questions from Challenge 2 that required players to read information from posters.

The following post-simulation questions were ranked and scored similarly.

Table 9: post-simulation survey answers

question	Average score
What is the common name for sodium hydroxide?	1.692
What colour does caesium burn?	0.923
What is the half-life of francium?	0.154

These results show that participants who completed Challenge 2 did learn the common name for sodium hydroxide. Those who completed Challenge 3 exclusively, learnt flame colours completing LO4. Finally, only one person read the francium wall poster, but no one remembered its content.

5.4 DATA VALIDITY

This study completed all research objectives: full comprehensive surveys were utilised with less than 15 questions; and the collated data shows that users were satisfied and retained taught knowledge. It shows that fully immersive simulations do allow people of all ages and backgrounds to engage and enjoy learning. However, due to the small sample size, these results may not fully represent the capabilities of this project. Additionally, the two survey format using mainly multiple choice questions enables participants to randomly guess answers correctly, again skewing results. Both issues would be diminished, by rerunning the trials to increase sample size.

Finally, due to the networking protocol issues, all of the trials had interruptions due to network issues and 3 even crashed in the multiplayer environment. Those who crashed were given the option to continue in singleplayer. No further information about the study was released between play sessions so survey answers shouldn't have been affected by this.

6. CONCLUSION

This project successfully completed its aim: the games development was fully realized with few issues in the final build; and all work packages, necessary game objectives, and most conditional game objectives were completed. This meant that the final game was in its best possible form for testing, with 3400 custom objects and 40+ C# scripts in use. Participants in the tests believed the game was both entertaining and educational, and participants who progressed through the challenges showed distinct improvements in their retained knowledge. This led to an average score increase of 24% between the pre- and post-simulation quizzes. Overall, this shows that non-serious gaming can be both educational and fun. It has highlighted that, at least on a small scale, gamification can be an effective method of teaching in fully immersive VR, completing this study's secondary aim. While the multiplayer element was generally well received, it created distractions, which lowered participant engagement. That said, no participants became majorly distracted during their trials, and everyone engaged with the educational aspects of the game. Read information, such as posters, was the most neglected learning method, while direct action, such as burning or submersion, was the most common. This shows a general preference for interactive teaching.

All research objectives were completed. This showed that participant moderators affect interactions with predictors, decreasing mediators leading to failing criteria. This meant participants with poor VR efficacy struggled to complete targets, concurring with launders et al.[5]. This study provides an interesting basis for future research into this mode of gamification: creating a game and implementing educational content. To address the limitations of this project caused by the small sample size and network issues, the project should be retested, aiming to target a much larger population, and measure long term knowledge retention through repeat trials.

An interesting further study would be the design of a larger game universe in which the player is taught more of the GCSE chemistry curriculum, and their knowledge recall is tested over a longer period. This study would enable participants to directly learn, by choice, in the pursuit of entertainment. It would also judge the efficacy of this learning method on the long-term memory. To this end, the fracturable, dissolving, and burning functions can be easily adapted for other simulations. This would enable researchers to create new 'real physics' games and complete further research in the field.

ACKNOWLEDGEMENTS

Thanks to Simon Lawes for supervising this project and going above and beyond in supporting me through difficult times, and answering my many, many questions.

Additionally, thanks, to Chirstopher Brooker, for aiding with the Multiplayer and Networking issues by being a helpful liaison with the IT staff, helping with marketing posters, and allowing and overseeing the use of the VR classroom for this project's testing.

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APPENDIX 2 – EDUCATIONAL POSTERS

2 examples of posters used around the classroom

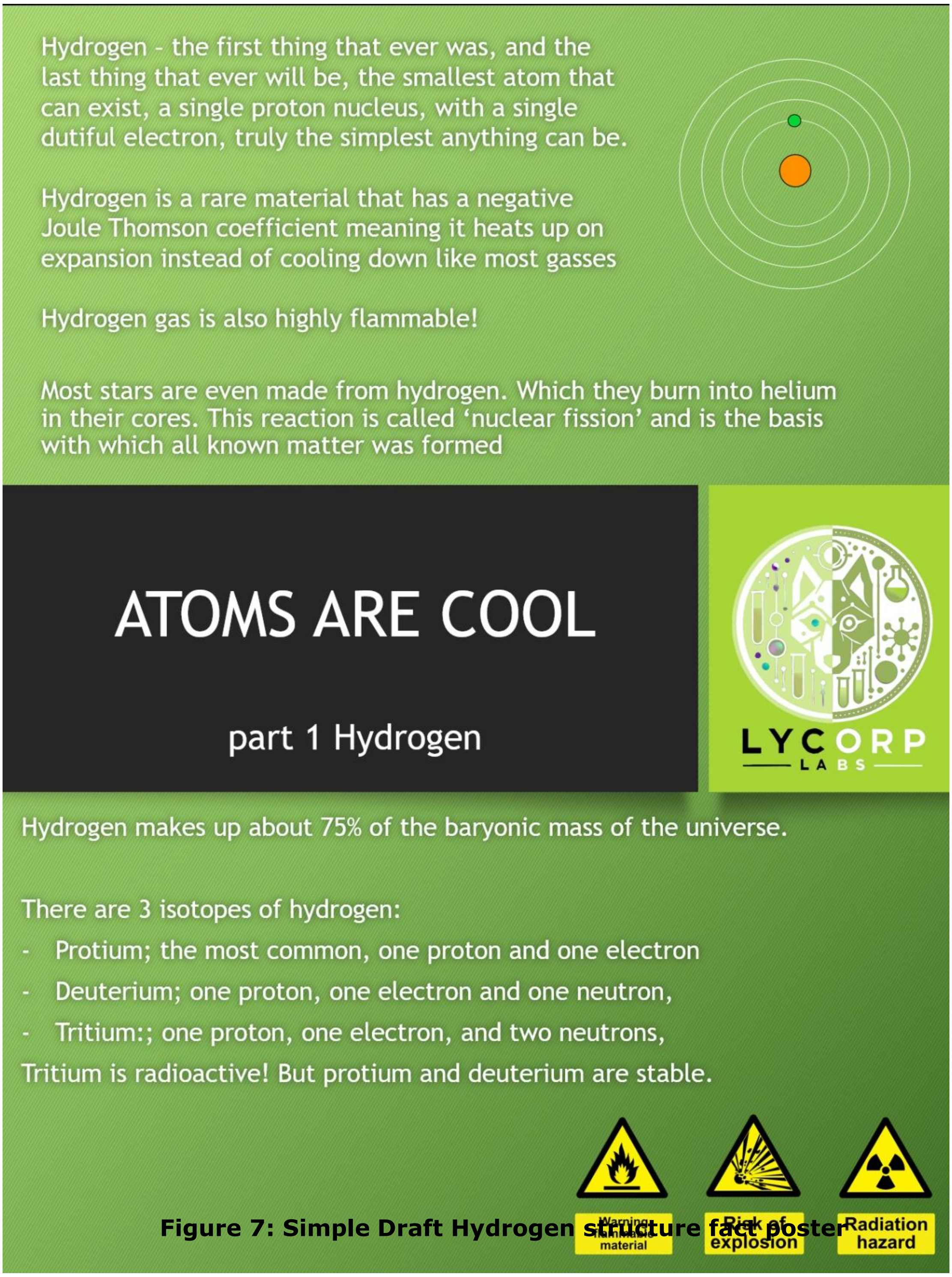

Figure 7: Simple Draft Hydrogen structure fact poster

Figure 8: Simple Draft Alkali Metal Guide

APPENDIX 3 – ETHICS APPROVAL

Ethics Committee Reviewer Decision

This form must be completed by each reviewer. Each application will be reviewed by two members of the ethics committee. Reviews may be completed electronically and sent to the Faculty ethics administrator from a University of Nottingham email address, or may be completed in paper form and delivered to the Faculty of Engineering Research Office.

Applicant full name: Daniel Menadue

Application Number: 2025-49 Menadue

Reviewed by: K08

Signature (paper based only) ……………………………………………………………………………………………

- [ ] Approval awarded - no changes required
- [x] Approval awarded - subject to required changes (see comments below)
- [ ] Approval pending - further information & resubmission required (see comments)
- [ ] Approval declined – reasons given below

Comments:

The study can proceed, subject to the following amendments.

It is unclear what will happen to participants who indicate they have epilepsy. Whilst there is not clear evidence that seizures are more commonly triggered in VR than in conventional television, for those with photosensitive epilepsy, it may be a concern. I would encourage participants with photosensitive epilepsy who want to take part to seek advice from a medical professional before taking part. I would also encourage you to ask participants about their propensity for motion and/or simulator sickness ahead of the trial.

Further, in future – **do not begin advertising for studies prior to ethics approval.** I have already seen advertising for this around campus.

Any problems which arise during the course of the investigation must be reported to the Faculty Research Ethics Committee

Figure 9: Proof of ethics committee approval

APPENDIX 4 - MARKETING POSTERS

This poster was used to market the game on pin boards and as flyer leaflets

Figure 10: The original poster dystopian poster

This poster was used on the University TV- billboards

Figure 11: this poter was used on the universitys electronic billboards

APPENDIX 4 - NETWORKED FRACTUREABLE FUNCTION

The fracturable function takes the kinetic energy of an impact to determine if an object has fractured. Only the person who currently 'owns' the object can be allowed to do this. Otherwise, every client tries to smash it concurrently, overloading the server with duplicated RPC's.

If the owner believes it has fractured, the ‘BreakTheThingRPC’ is called. This function executes on the server. This function tells all clients to disable the object. Then the server spawns the fractured model in and teleports it into position. The r&c droids must only run on the server, constantly scanning their respective list for new objects, determining which object is the closest to their current location and then moving towards it. Client side r&c droids are effectively ‘shells’ that perform no computation at all. They are just fakes that dragged around by the server through synced position and rotation. This method is graphically explained in the figure below, starting with client 1 dropping a conical flask:

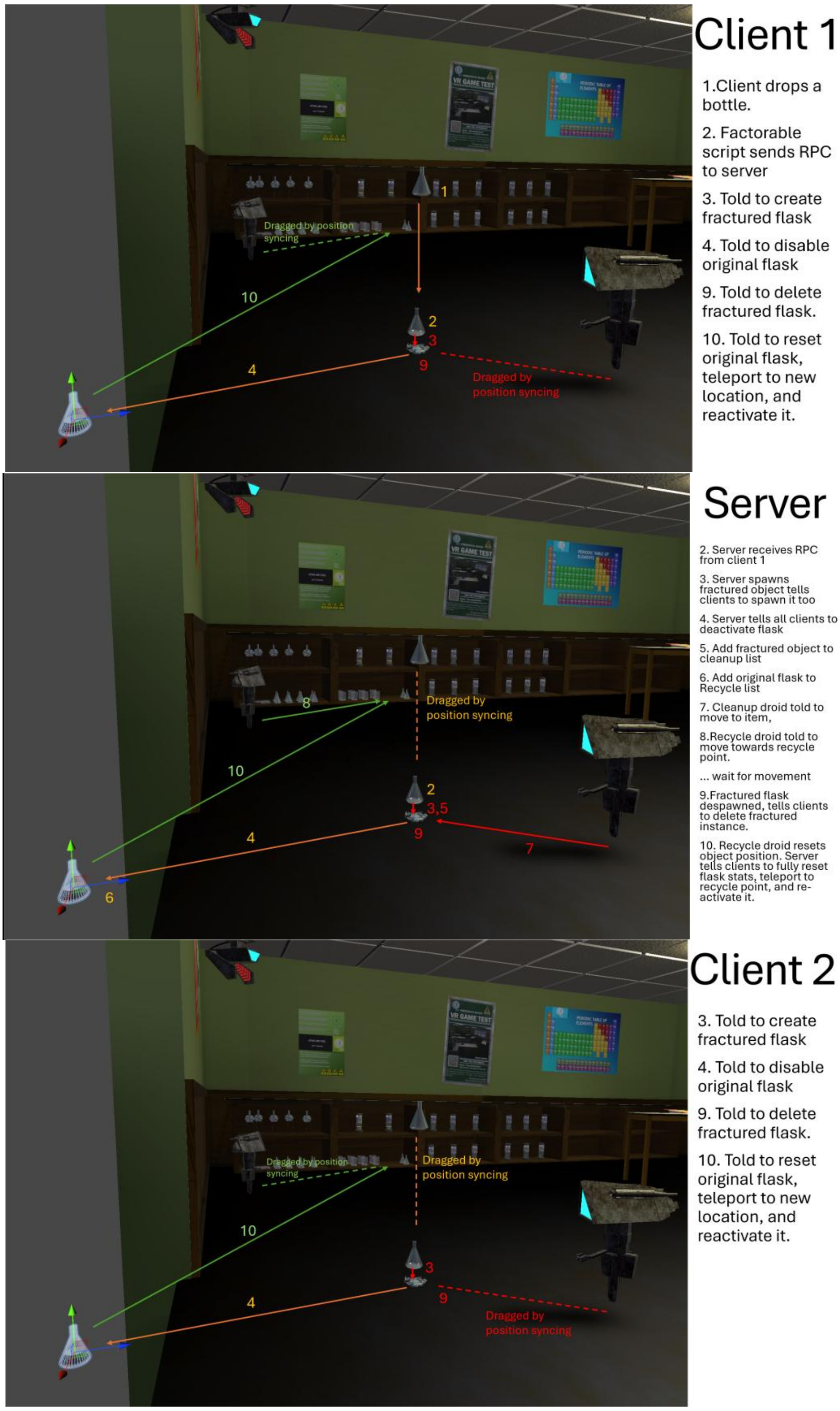

Figure 12: A description of the fully networked fracturable function

