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The Co-IMMUNicate App: an engaging and entertaining education resource on immunity to respiratory viruses

Orla McCorry

School of Simulation and Visualisation, Glasgow School of Art, Glasgow, UK

o.mccorry@gsa.ac.uk

Kerrie Hargrave

Centre for Immunobiology, University of Glasgow, Glasgow, UK

kerrie.hargrave@glasgow.ac.uk

George E Finney

Centre for Immunobiology, University of Glasgow, Glasgow, UK

g.finney.1@research.gla.ac.uk

Rowan Patterson

Anderston Primary School, Glasgow City Council, Glasgow, UK

gw14pattersonrowan@glow.ea.glasgow.sch.uk

Anna Cain

Anderston Primary School, Glasgow City Council, Glasgow, UK

gw10cainanna@glow.ea.glasgow.sch.uk

Matthieu Poyade

School of Simulation and Visualisation, Glasgow School of Art, Glasgow, UK

m.poyade@gsa.ac.uk

Megan Kathryn Louise MacLeod

Centre for Immunobiology, University of Glasgow, Glasgow, UK

Megan.Macleod@glasgow.ac.uk

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Abstract

Co-IMMUNicate is a multi-layered engagement project with input from academics, teachers and pupils at a Glasgow primary school. The project is designed to ensure sustained impact on the school and local community, and increase knowledge of the importance of immunology research in protecting us against infectious diseases. The project aimed to enable pupils to design and build activities to teach and enthuse younger children and their families about the immune system through displays in the school and across Glasgow. Working across disciplines and ages, we have generated numerous resources and best practices. These resources include the 'Co-IMMUNicate App' which uses augmented reality, quizzes, and a fun game to help us more widely disseminate Co-IMMUNicate's aims. This chapter describes the methodological and technological framework to support the development of the Co-IMMUNicate application.

We designed and developed this application to engage and excite children about immunity to infection. A co-design approach was used to incorporate ideas from the primary 6/7 school children. They provided drawings to illustrate what happens after a respiratory virus infection and additional drawings to illustrate the quizzes. The pupils have also provided application voice overs to help increase the application's accessibility. Their initial comments and feedback from testing the aplication shaped the design of the application and provided them with a sense of ownership.

The application contains four main elements: an Augmented Reality section in which the user can learn about what happens during a respiratory virus infection; a quiz based on the learning in the first section; a second quiz that helps the user learn about how small viruses are; and an interactive game in which immune cells capture invading viruses. Users who complete the augmented reality section and the two quizzes are rewarded with a certificate.

Keywords: public engagement, co-design, Augmented Reality, educational application, immunology.

1. Introduction

When pathogens infect the body, they trigger an immune response that usually leads to pathogen control and clearance. As part of this response, specialised immune cells that can specifically recognise the pathogen are triggered. These so-called 'adaptive' immune cells are trained during the infection and some of them continue to reside in the pathogen-targeted tissue. These 'super-defenders' can provide rapid protection to a future infection as they remember their training from the first response (Gray et al., 2018). This memory of past infections is the mechanistic basis for the success of vaccination (Iwasaki and Omer, 2020).

We know a lot about how cells of the immune system are activated but still have a lot to learn about how they work with other cells within pathogen-targeted tissues (Gray et al., 2018). This is important research as improving our ability to defend the body from infectious disease and reducing or prevent the morbidity and mortality that infectious diseases, including SARS-CoV-2, cause. It is vital that we communicate the importance of this type of scientific research to the public for two reasons (Wynne, 2006). First, much of this research is funded by charities or government-funded research bodies. We have a duty to share the positive impacts of our research with the public to ensure they agree that this is a good use of their taxes and donations. Second, the success of public health measures, such as vaccines, requires the engagement of the public to participate. An informed public that understand what vaccines are and how they work, are much more likely to approve of and take up opportunities for vaccination (WHO,2017). We aim that our engagement activities build upon successful communication between researchers, school teachers, and the youth.

We have been working with the teachers and pupils at Anderston Primary school in Glasgow. Together we have created activities and displays that communicate complex ideas about immunity to viruses and how communication within the body is vital to the success of vaccination. We have created a multi-layered engagement project ensuring sustained impact on the school and local community, increasing knowledge of the importance of immunology research to protect us against infectious diseases. We aim to enable pupils to design and build activities to teach and enthuse younger children and their families about the immune system. We have done this through displays in the school, across local communities, and via an online resource charting the journey of our project. Working across disciplines and ages, our project has generated numerous resources and best practice that we are sharing with the wider community (University of Glasgow, 2022).

One of the major objectives of the research has been to create a mobile application that communicates to the user the consequences of respiratory virus infection in a fun and informative format. This chapter presents a methodolofical and technological framework for the implementation of such application.

1.1 Related Work

With the increasing prevalence of mobile technologies across communities, it has become ever more convenient to use such technologies to engage with targeted audiences through both, educational and public engagement resources (Martin, 2012; Bernacki et al., 2020). This trend has also been confirmed for younder audiences fostering them to achieve higher degrees of motivation and further engage with the exploration and understanding of challenging scientific concepts (Khan et al., 2019; Kalogiannakis et al., 2018; Fuchsova & Korenova, 2019).

Different approaches are currently being explored to foster motivation and facilitate learning among scholars, using serious gamification (Molnar & Kostkova, 2018) and/or mobile virtual and augmented reality (AR) (Connaghan et al., 2019; Degli Innocenti et al., 2019; Fuchsova & Korenova, 2019; Hassan et al., 2021). It has recently been suggested that AR-based education promotes motivation and education performance more effectively compared to non-AR learning (Muhammad et al., 2021).

AR consist of a technology which enables the overlay of digital graphical elements on the real-world (Azuma, 1997). AR can be experienced using optical see-through devices such as dedicated head-mounted display or goggles, or simply using video see-through devices such as the now widely available smartphones and tablets (Pierdicca et al., 2017). In the last case, AR adds an overlay of interactive digital elements onto a screen capture of the real world and bridges the gap between the digital and physical world (Cipresso et al., 2018). AR can be Marker-based, which uses target images or 3D object recognition algorithms as the initiator for the AR overlay (Cheng et al., 2017); or Markerless, which relies on either the detection of characteristic points within the real-world without any previous knowledge of the environment (Oufqir et al., 2020), or the ability of geolocation (Boonnrahm et al., 2020).

Viruses, which cannot be seen by the naked eye, are challenging to mentally viusalise and it is believed that the development of scientific communication resources could greatly impact their conceptualisation and understanding among the public (Slater et al., 2022).

To the knowledge of the authors, there have been limited research using mobile AR to support effective communication and enhance the development of knowledge about microbiology and immunology among the public, and more particularly among younger audiences. There have been some recent endeavours to develop graphical resources to provide insights into viruses (Slater et al., 2022), which included components of augmented visualisation – the Visible Virus AR App (Available at https://cvrblog.myportfolio.com/visible-viruses-ar-app). This application uses educational posters as AR markers to trigger the overlay of 3D models of Zika, Herpes and Influenza viruses. Tsaramirsis et al. (2021) have developed a markerless AR simulator to help people gain basic understanding of viral spread of coronavirus, displaying hypothetical contamination overlaid onto the real world. Rapp et al. (2018) presented a collaborative AR game experience which engaged players in a quest to find image markers within a play area to trigger augmented animations or ingredients which would allow them to prepare virus antidotes. Although they concluded the game fostered high level of engagement and playfulness, measures of educational value or knowledge gained by the users weren't undertaken during the study. Lima et al. (2017) have proposed a gamified approach which used marker-based AR to educate the player about control measures against the dengue virus throughout the lifespan of the game protagonist. Despite an interesting game design being presented, further research is needed to validate these approaches.

Our focus in this research is to effectively engage younger children with the subject of viruses and help them to learn how their body reacts to defend itself against a respiratory virus attack.

2 Methods

2.1 Workflow

This project builds upon a collaborative approach involving primary school children to devise the mobile application. Fig. 1 presents the workflow that enabled the development of the mobile application.

Figure 1 – Workflow diagram used to create the application following a co-design workshop.

2.2 Co-Design Workshop

A collaborative design workshop was scheduled as an in-class activity for a cohort of 16 pupils aged 9-10 years old from the Anderston Primary School, Glasgow, UK. Aiming at developing the pupils's sense of ownership, this workshop offered the opportunity for the pupils to provide their inputs into the graphical design of the application, propose activities and define interaction paradigms.

2.2.1 Procedure

The workshop took place online via Teams. The pupils were in their classroom in front of a wide TV screen equipped with a webcam to facilitate communication with the resarchers.

The workshop began with a brief overview of the interactions between the reearchers and the class the previous year. Following this, the concept for the AR application was introduced inclusive of the aims and objectives of the project. The pupils were informed that their help was required to design the application, and that they would therefore be asked to take part in discussions and creative activities during and beyond the workshop.

In the first instance, the pupils were asked to acknowledge small and large items they related to, that could be used as reference in the application to highlight how small viruses are. Then, the pupils were introduced to Augmented Reality via two short videos: (1) An AR version of the hand-eye coordination board game Operation from Hasbro, in which a player aims to pull out plastic-made symbolistic anatomical structures from a comic made up to look like a patient, using electric wired tweezers without touching the edge of the cavity opening. This development was the main outcome of the MSc project of the main author; (2) A digital model of a sports car overlaid onto a mobile phone screen capture of the real world, which was part of the teaching material from the Human Computer Interaction and Virtual and Augmented Reality course at the School of Simulation and Visualisation, the Glasgow School of Art. Building upon these, the pupils were asked whether they frequently used mobile technologies and knew of Augmented Reality and applications using Augmented Reality. They were also asked whether they believed Augmented Reality could help make their learning more engaging and motivating ,for instance, in the filed of life sciences.

Afterwards, the researchers explained to the pupils how Augmented Reality could be used in the application, overlaying digital models onto image patterns, t-shirts and posters, but also in the real world. Finally the pupils were informed that beyond the workshop, they would be asked to provide a list of graphical (icons, button, banner and background images) and audio assets (voice-overs). They would therefore be requested to engage into creative drawing activities to produce drawings of these graphical assets using Procreate on their school's iPads, and audio recording of the application textual content.

2.2.2 Data Analysis

All data from the workshop were collected in an excel sheet and redundancy of response was annotated. The pupil's responses and their interpretation made by the researchers would then be fed-back to inform about the graphical and audio assets to be produced beyond the workshop.

2.2.3 Results

When asked to identify small and large items with which they could relate to, the pupils reported the items in Table 1. The proposed small items included conventional object references such as a pencil lead or an ant, towards local insects as midges, whereas the proposed large items mostly consisted of local landmarks.

Table 1. Small vs Large Items being proposed by pupils

Small Items	Occurrence	Large Items	Occurrence
Leaf	1	Finnieston Crane	2
Sand	1	Glasgow Science Centre Tower	2
piece of thread	1	**SSSC Hydro**	**2**
Pencil Lead	2	Art Gallery	1
IPad	1	Glasgow Science Centre main Build-ling	2
Midge	**1**	Glasgow University Tower	1
Caterpilar	1		
Ant	1		

Further discussion with the pupils aimed to find a consensus about which proposed items were the most relevant to them. The midge, a west Scotland fly, and the SSSC Hydro, a local concert hall, were unanimously agreed to be the most most representative items to be compared to the size of viruses.

Overall, the pupils appeared to have little confidence about their ability to define Augmented Reality with only two children reporting an accurate definition of Augmented Reality as an interactive experience in the real world involving computer generated information. In contrast, they seemed to be much more knowledgeable about other applications mentioning Pokemon Go and Lego as major applications in the field, and also stated alternative use of the technology as “name above the head of every students in AR”, “costume trial”, “make some kind of landscape right behind you and pretend you are there”, “You can pretend you have superpower, showing your hand, it can be scanned and provides you instructions”, and “pretend you have every type of pets imaginable (e.g. dinosaurs)”.

They also propose “see virus in your hand in AR” when relating to the project.

Building upon the discussion, the pupils came with a set of features such as Augmented reality on t-shirt similar to Borovanska et al. (2020), Augmented Reality markers used to trigger quiz questions, and a 2D game in which the player would help a cell to defend itself from viruses using touch joystick on the tactile interface.

Finally, the pupils were presented with a series of graphical assets to be digitally designed within a month after the workshop. This list of graphical assets included: The application Logo (Fig. 2), 7-10 Viruses Drawing that can be used through all the application (Preferably drawn on white background) (Fig. 3); 2-3 Healthy Cells and lungs that can be used through all the application (Preferably drawn on white background) (Fig. 4 and 5); and the buttons for the Augmented Reality feature (Fig. 6), Size comparison (Fig. 7), and Trivia Quizz (Fig. 8).

Figure 2 – Logo button artwork drawn by the pupils at the co-design workshop.

Figure 3– Virus artwork produced by the pupils during the co-design workshop.

Figure 4 – Healthy cell artwork drawn by the pupils during the co-design workshop.

Figure 5 – Healthy lungs artwork drawn by the pupils during the co-design workshop.

Figure 6 – AR artwork and button drawn by the pupils during the co-design workshop.

Figure 7 – Size comparison artwork drawn by the pupils during the co-design workshop.

Figure 8 – Trivia button artwork drawn by the pupils during the co-design workshop.

After the workshop, the pupils were presented with a rough storyboard (Fig. 9) of the experience and a list of the written content to audio record for the voice-over feature of the application.

Figure 9 – Storyboard presented to the pupils after the workshop.

2.3 Application Design and Development

2.3.1 Concept

The application is targeted at children of ages 7-12 to teach them about the immune response to viruses. To achieve this a fun, interactive and educational application was created. The application was to include an AR animation, a trivia scene, a game and the Big vs Small scene. All these scenes would be accessible from an Index scene. A diagram was created (Fig. 10) to show the flow through the application.

Figure 10 – Diagram showing the scenes of the application and how the user would flow through between them.

The user is rewarded for completing each of the Trivia, AR animation and Big vs Small scenes with a stamp. Collecting all stamps will reward the user with a personalised certificate declaring them an 'Expert Immunologist'.

2.3.2 Colour palette

The colour palette (Figure 11) of this application was based around two pale shades of pink which would be used to colour the lungs. As this application is about respiratory viruses, the lungs will feature quite heavily within the application so it was important to have a strong colour palette that complemented the lungs. Green and purple were chosen as the primary colours for the viruses. These two colours, and purple in particular, is a colour completely foreign to the lungs and can easily be used as a contrasting colour to the pale pink.

Figure 11 - The colour palette used within the application.

2.4 Application Implementation

2.4.1 Materials

Table 2 shows the materials used to design and develop the App.

Software	**Use**	**Developer**
Unity 2019.4.13f1 With AR Foundation, AR Kit and AR Core 2.2.0 preview 6 asset packages installed.	Game Engine used to develop the application for both iOS and Android.	Unity Technologies Available at: unity3d.com
Visual Studio Code	Coding software used in conjunction with Unity to develop the application.	Microsoft Available at: https://code.visualstudio.com/
Procreate	Drawing Software used to draw the artwork and animation for the application.	Savage Interactive
Autodesk 3D Studio Max	3D modelling software used to create the 3D questionmark models for the Trivia Scene.	Autodesk Available at: https://www.autodesk.co.uk/products/3ds-max/overview

Seesaw	Audio recording software used to record the voice over.	https://web.seesaw.me/
Cartoonify	Cartoon images of the researchers were created using this website.	Available at: https://www.cartoonify.de/
Assets	**Use**	**Creator and Link**
Joystick Pack	Joysticks for the Cell Defender game scene along with the C# scripts which control the movement of the joysticks.	Fenerax Studios Available at: https://assetstore.unity.com/packages/tools/input-management/joystick-pack-107631
Hardware	**Use**	
iPad Pro and Apple Pencil	Used to draw the animations and artwork of the application with Procreate.	
ASUS VivoBook Laptop	Computer used to develop the application using the above software.	

2.4.2 Artwork

During a co-design workshop, the school children were asked to design characters, viruses and buttons that would be incorporated into the application. The idea behind this was to give the children a sense of ownership of the application when they saw their artwork.

To incorporate the artwork into the application, the artwork was simply traced so they were all in the same style, and the colours were changed to fit into the colour palette (Fig. 12).

Figure 12 - A virus drawn by a pupil on the left, and the same virus redrawn and coloured on the right that is used in the App.

2.4.3 Title scene

Initially used as button artwork, Fig. 13 served as inspiration for the logo of the application. The logo is a large, simple virus with the name of the application across the centre.

Figure 13 – A button drawn by pupils (left) that inspired the logo of the application (right)

A title scene was created as the launching point for the application. The App logo was placed in the centre of the screen. A simple rotating animation was added to the logo to add some movement to the title screen.

Three buttons were placed in the Unity scene: ‘Quit’, ‘About’ and ‘Start’ buttons. An ‘About’ panel was created with information about the project and the people involved. Cartoon portraits of the project team were made using https://www.cartoonify.de/ and used on this panel alongside the logos of the organisations involved in the project.

Another UI panel was created in Unity to welcome the user to the application. An input field was added for the user to enter their name. This name is stored in the application using UserPrefs for the purpose of using the inputted name on the end certificate. The name is not stored outside the application or used elsewhere. A continue button on the panel opens the Index scene.

2.4.4 Index Scene

This Unity scene was set up as a menu to access the other four scenes. Four buttons were placed in the centre of the screen which each launches one of the four scenes.

An empty gameobject was created with a script that controls and stores UserPrefs that correspond to the users progress through the application, in particular the Learn in AR, Trivia and Big vs Small scenes. Completing a scene sets a specific UserPrefs integer from 0 to 1 and sets an animated 'stamp' graphic active on the index scene. This stamp consisted of a visual representation of that scene having been completed. The pupil's artwork of healthy cells (Fig. 4) were used as the graphics for the stamps. Three separate 'stamp' graphics were placed beside their corresponding scene button and set as inactive.

A UI panel was created with the end certificate graphics and a UI text that displays the name of the user that they inputted in the title screen. This panel displays the three 'stamp' graphics the user would have achieved and congratulates them for completing the application. A close panel button was added to the top of the screen. There is also a 'Reset Progress' button at the top of the panel that resets the UserPrefs of the application, removing the progress made by the user and resetting the UserPref integers to zero. This panel was set as inactive.

Finally, a fifth button was added to the index scene below the other four that sets active the certificate if all three stamps have been collected – i.e. each of the Trivia, AR animation and Big vs Small scenes have all been completed. If these scenes have not been completed yet, the button would remain inactive or invisible and the end certificate is would not be accessible.

2.4.5 Learn in AR

This is the primary learning scene and main feature of the application. The concept was to create an animation that would communicate how immune cells in the lungs would respond to a respiratory virus. To work within the time limit of this project, the development of a 2D animation was prefered over 3D animation.

A short script was first developed by one of the immunology researchers. From this script, a detailed storyboard was made. This specifically detailed storyboard (Appendix 1) was inspired by one of the drawings by the pupils of personified lungs (Fig. 14). A mock-up of what the animation style would look like was made showing the personified pair of lungs waving.

Figure 14 - The pupil's artwork of a pair of personified lungs on the right, and the artwork created for the animation on the left.

The animation was then fully developed into nine short sections that corresponded to the script and drawn with an Apple Pencil using Procreate on an iPad Pro. Hand-drawn sequences of sprites were imported into Unity and animated using the Animator tab.

Each sequence of animation was given a C# script component that attached a corresponding UI panel with the text from the script. The first sequence – a looping animation of the lungs waving – was given a blank UI panel as this sequence has no corresponding text. Each UI panel was given a continue button. When pressed, the next section of the animation was set active along with the next UI text panel (Fig. 15). This ensured the flow of the animation was in the correct order. It also allowed the user to watch the animation in full, read at their own pace and click continue when they were ready.

Figure 15 – Development image from the AR animation scene. UI panel with text from the script along with a placeholder sprite for the animation used when testing the flow of the sequences of animation. The continue button is in the lower left-hand corner which triggers the next UI panel and animation sequence.

The last UI panel, connected to the ending sequence in the animation, was given an end button that triggered a UI panel with options to restart the animation or to return to the index scene. Additionally, when this button was pressed, UserPrefs would set the 'ar' integer to one. By doing this, a stamp is set active on the Index scene and the user has completed one step to unlocking the certificate.

A cube gameobject was placed at the centre of the scene and the mesh renderer was set not active to make it invisible. This cube was created to be the parent gameobject for the animation seuqneces so they would all appear in the same position and at the same scale when they are set active. Each sequence of animation was made a child of the cube, ensuring they would appear in the centre of the scene (Fig. 16). The cube was then scaled appropriately to show the animation at the correct scale. The first sequence was set active, with the consecutive sequences set not active. The parent cube gameobject was then set not active, leaving the scene blank.

Figure 16 – Unity interface showing the hierarchy and the scene view of the Learn in AR scene. The green outline is the cube gameobject ("Platform" in the Hierarchy) that is the parent to all the animation sequences (0-8 AnimationSprite in the Hierarchy).

This scene in the application uses marker-based AR. The Co-IMMUNinicate logo was chosen to be the marker for the learning scene.

The AR components were set up in the Unity scene. AR Foundation subsystem was downloaded into Unity along with AR Core and AR Kit subsystems for each development platform, respectively iOS and Android.

An AR Session and AR Session Origin were added to the scene. The AR Session Origin was given an AR Tracked Image Manager component. An AR Reference Image Library was created using the Co-IMMUNicate Logo, and was linked to the AR Tracked Image Manager component. The AR Session Origin was also given a script component which set active the cube gameobject when the AR marker is seen by the camera of the tablet device. The cube gameobject and its children are set active when the tracking state of the AR marker was Tracking, and would be set not active when the tracking state was either limited or none. Therefore, if the tablet camera clearly showed the Co-IMMUNicate logo, the invisible cube would be set active and the first animated sequence of the lungs waving would appear over the logo.

Lastly, an instruction panel was created as an introduction to the scene. The panel was given text to tell the user how to use AR with the camera of their tablet device and the AR marker. With the tablet camera showing the marker, 2D sprites of the lung characters appear. The user is asked to click the first continue button once they can see these lungs. A close button was added to this panel that sets the panel not active. A home button that takes the user back to the index scene and a mute button to mute the voice over, were also added to the top left hand corner of the scene.

2.4.6 Trivia

To test the user's knowledge of immunology from the content of the application, a trivia scene was added in Unity. Six total questions were made: four multiple choice questions and two true or false questions.

An empty gameobject was created called 'CertificateManager', with a script component containing six bools all set to false. These six bools correspond to the six questions.

Six UI panels were created, each with a different question written in a text component. For the multiple choice questions, three buttons were added to the panel with three different answers (Fig. 17). A small panel was added to this screen that tells the user to choose another answer, and was set as inactive. If either of the two incorrect answer buttons are pressed, this small panel is set active and the button is set and uninteractable. A short animation was placed above the correct answer and set not active. If the correct answer button is pressed, the short animation is set active to signal to the user they have chosen the correct answer. The two other answer buttons are made uninteractable and the continue button is set as active. The continue button closes the panel and sets the corresponding bool to true from the CertificateManager.

Figure 17 – Trivia question panel showing the initial layout of the question and three answer buttons.

The two true or false question panels are set up the same was but with two answer buttons instead of three. All question panels are initially set as inactive.

An ending panel was created to congratulate the user for completing all the questions and rewards them with a stamp towards becoming an expert immunologist. This panel is set as active when all six bools on the CertificateManager are true using the scritpt attached to this empty gameobject, as well as setting the UserPrefs 'trivia' integer to equal 1. This activates the corresponding stamp on the index scene. Two buttons are also placed on this ending panel that either take the user back to the index scene or restart the trivia scene. Restarting the trivia scene resets the CertificateManager Boolean variables but does not reset the UserPrefs 'trivia' int to 0. This allows the user to go through the scene as many times as they like but does not take away the progress they have made through the application.

An introduction panel was created to welcome the user to the scene and instruct them on how to use the AR correctly. A continue button was placed that sets this panel not active when clicked. This allows the screen to be entirely filled with the feed from the device camera.

A 3D model of a question mark (Fig. 18) was created in 3D Studio Max and imported into Unity as an obj file. The question mark was placed in the centre of the scene and scaled to the Appropriate size. The question mark was then duplicated five times to make 6 question marks. Each question mark was given a different coloured material and numbered one through six. A C# script component was added to each questionmark so that it controls the activation of a UI question panel when the questionmark is tapped on using touch interaction. Each question mark was assigned a different question panel. All six question marks and their corresponding UI question panels were set as inactive.

Figure 18 – 3D model of a question mark created in 3Ds Max.

The AR components of the scene were set up similarly to those in the Learn in AR scene, with an AR Session and AR Session Origin. Another Reference Image Library was created using six AR markers. Six of the virus illustrations the pupils drew were chosen to be used as AR markers. This Reference Image Library was assigned to the AR Tracked Image Manager component of the AR Session Origin. A C# script was also attached to the AR Session Origin that connects one question mark to one specific AR marker. This C# script sets a connected question mark active when the tracked image state of the AR marker is either tracked or limited. If the tracking state is none, all question marks are initially set as inactive.

As with all scenes, a mute button and a home button that returns the user to the index scene were also added to the top left hand corner of the screen.

2.4.7 Big vs Small

This scene was developed to give the user an idea of how small viruses are in comparison to larger structures: a cell, a midge and the Glasgow Hydro.

Five UI panels were created in Unity: an introduction panel, three question panels and an end panel. The introduction panel contains text that tells the user about the scene and a continue button that triggers the first question panel.

On each question panel, there are three buttons with three different answers in numbers (Fig. 19). To add visual reference to the answers, images were added above each button which show either a cell, a midge or the Glasgow hydro. These images also show viruses, with the larger number answers showing more viruses than the smaller numbers.

Figure 19 – Big vs Small question panel during development with basic button functionality and without numerical answers.

Similar to the trivia scene, if the wrong button is selected, the button is set as uninteractable and a small panel appears that tells the user to select another answer. If the correct button is selected, the lung characters from the Learn in AR animation appear in the bottom left corner as an animation, celebrating that the correct answer is chosen. A continue button appears and pressing it sets active the next question panel. In the case for the last question, the end panel is set active. This button also sets the UserPrefs integer 'bigsmall' to 1, signalling that the scene has been completed.

The end panel congratulates the user for completing the section and rewards them with a stamp towards becoming an expert immunologist. Two buttons were placed on this panel to either restart the scene from the introduction panel or to return the user to the index scene. Again, a home button that takes the user back to the index scene and a mute button to mute the voice over, were also added to the top left hand corner of the scene which is visible in all panels.

2.4.8 Cell Defender

To increase the time spent within the application, a game was included. As this is an educational application, the game was based on the taught content in the application – the immune response to viruses. Antibodies on immune cells are the user characters which will encourage the user to see the antibodies positively as the "hero" of the game, and the viruses negatively as the "enemy".

The concept behind the game is a children's playground game "Protect the President". In the game, viruses will enter the lungs and circle around an immune cell. The user will control antibodies on the immune cell and try to "catch" the virus as it Approaches the cell, effectively protecting the lungs. By catching a virus, the user scores points with the aim of catching the most viruses within the time limit.

An alpha version was developed to pilot the idea. A 2D circle spite was placed in the centre of the screen (centre sprite). A second, smaller circle spite was made a child of the centre sprite and positioned slightly above it. A C# script (Fig. 20) was attached to the smaller circle (Antibody) to rotate it around the centre sprite using the arrow buttons and the RotateAround() function and the position of the centre spite. This is the users basic movement of rotating the Antibody clockwise or anti-clockwise.

Figure 20 – C# Script function that controls the users movement of rotating the Antibody around the centre sprite.

An empty gameobject, named spawner, was added to the scene and positioned further above the centre sprite with a C# script that continuously rotates around the centre sprite at a slow pace, as well as spawn "enemy" sprites using the Instantiate() function. The "enemy" spite was given a "virus" tag and spawns every six seconds.

Once the "enemy" sprite spawns, it moves towards the centre sprite. To achieve this, a vector3.MoveTowards() function was used with the centre sprite position.

If the Antibody collides with an gameobject with tag "virus", that gameobject is destroyed. If the "enemy" sprite collides with the centre sprite, the "enemy" sprite is also destroyed.

This is the basic functionality of the game, with "enemy" sprites spawning and moving towards the centre sprite, and the user protecting the centre sprite by rotating the Antibody around to collide with the "enemy".

After the alpha version, the game was fully developed for touch screen.

A plane was created and scaled to fit the screen for the background of the scene in Unity. A large image of a pair of lungs and trachea was drawn, imported into Unity and used as a material on this plane. The alpha version centre sprite and accompanying Antibody and "enemy" spawner were scaled to fit inside the left lung.

Joysticks controls were added to the scene to give the user control of the rotation of the Antibody which replaces the use of the arrow buttons (Fig. 21). The joystick assets were downloaded from the Unity Asset Store: Joystick Pack by Fenerax Studios. The movement remained the same, rotating the Antibody around the centre sprite clockwise or anti-clockwise.

Figure 21– Game scene in development showing the placement of the joystick controllers on either side of the screen.

The "enemy" spawner was positioned off screen above the top-middle of the background, i.e. above the trachea of the background image. The RotateAround() function was removed from the spawner so it no longer moves from its position but still spawns "enemy" sprites.

An animation was created for the “enemy” sprites which simply moves the “enemy” sprite into the lungs from the spawner using its Transform.position. The script on the “enemy” sprite tells it to complete the animation before rotating around the centre sprite, again using RotateAround() function and the co-ordinates of the centre sprite. This also triggers a bool (isRotating) to equal true and for the script to enter a coroutine. After a waitTime, isRotating equals false and a new bool – isMoving – is set to true. This bool triggers the “enemy” sprite to move towards the centre sprite. To add randomness to the game, the waitTime was set to a RandomRange. This means the “enemy” sprite changes from rotating around the centre sprite to moving towards it at a random time and random point in its rotation.

To increase the challenge, the user must protect both left and right lungs at the same time, using both hands action on two joysticks, located on either side of the screen. The centre sprite, Antibody, “enemy” spawner and Joystick were duplicated and positioned for the right lung. A new animation was created for the “enemy” sprites spawning on the right side so that they were correctly positioned in the right lung when they spawned.

The basic circle sprite images were changed to be the same as the ones used in the Learn in AR scene. The left side was differentiated from the right side by using green “enemy” sprites and a green Antibody, opposed to the orange of the other side.

A score counter and timer were added to the scene in the top right hand corner. The user was given 90 seconds to play the game and score as many points as they could. Points towards the score are made when the Antibody collides with the “enemy” sprite. It was decided not to deduct points for any “enemy” sprites reaching the centre sprite to not discourage the user. However, a short animation on the centre sprite of it looking unhAppy was added to provide negative feedback.

To add progress for the user, once the user has scored five points, a second Antibody is set active on each centre sprite. These second Antibodies move alongside the the original Antibody and have the same function of rotating around and protecting the centre sprite. This features signifies the immune cell (the centre sprite) developing immunity and becoming stronger. At the same time, reaching the score of 5 points triggers the “enemy” spawner to spawn viruses more quickly by shortening the waitTime between Instantiating an ”enemy” sprite. This aims to make the game gradually more challenging.

A congratulation panel would appear to inform the user about their final score. Two buttons were added to this panel, one returns the user to the index scene, and the other restarts the game by reloading the scene and resetting the score and timer.

A pause button was added to the top right-hand corner of the game scene. Pressing the button pauses the game by setting the Time.timeScale to 0f. This stops all movement within the game and the spawner. A panel would then appear allowing the user to immediately restart or return to the main. Pressing the close button on this panel resumes the game and closes the panel.

Finally, an introduction panel was created to inform the user about the game rules and interaction paradigm. Pressing a continue button on the panel closes the panel, begins the timer, and begins the game.

2.4.9 Voice Over

The pupils of Anderston Primary school provided voice overs to each item of text within the App. Parental consent was given to obtain these recording. These were made using Seesaw application and inputted into the corresponding sections in the Unity project.

3 Results

The result of this project was the creation of an application for both iOS and Android devices, that includes an educational, AR animation, two quizzes and a game. All sections of text within the application have a corresponding voiceover which was provided as part of the collaboration and co-design with Anderston Primary school pupils. These voice-overs increase the accessibility of the application, for example, for children who have difficulties with reading. The artwork within the application, including backgrounds, characters and illustrations are based on, or inspired by the illustrations drawn by the pupils at Anderston Primary school.

3.1 Title screen

The title screen (Fig. 22) is the launch pad of the application, showing an animated logo of the application along with four buttons. Pressing the ‘About’ button triggers a panel with more information about this project (Fig. 23) and the people involved in its creation. Pressing the ‘Quit’ button closes the application.

Figure 22 – Title screen of the application with the CO-IMMUNicate logo in the centre.

Figure 23 – About panel from the title scene.

Pressing 'Start' triggers a panel which introduces the content of the application and asks the user for their name (Fig. 24). This name will be used on the certificate at the end of the application and is not stored or used elsewhere.

Figure 24 – Welcome panel in the Title scene which introduces the application to the user and has an text input panel for the users name.

3.2 Index Screen

The user is presented with an index menu (Fig. 25) with four options: Learn in AR, Trivia, Big vs Small and Cell Defender. In every scene of the application, there is a home button in the top right-hand corner of the screen, beside the mute button. This home button either returns the user to the Index scene or to the title screen.

Figure 25 – Index scene which showcases some of the virus artwork by the pupils.

3.3 Learn in AR Scene

This scene is the main learning scene of the application. The user is first presented with an information panel explaining briefly how to trigger the AR animation using the Co-IMMUNicate logo (Fig. 26). The user will need to accept the use of their camera in the tablet.

Figure 26– Learn in AR scene introduction panel.

The animation (Fig. 27) is composed of nine short sections which explain how the immune system acts in response to a virus in the lungs. The user progresses through the nine sections at their own pace using the 'continue' button.

Figure 27 – Three images of the Learn in AR scene showing a user viewing three sections of the animation in AR and their corresponding UI panels.

At the end of the animation, a panel appears prompting the user to return to the index or to restart the animation.

3.4 Trivia Scene

The trivia scene is another AR-driven scene that tests the user's knowledge of immunity. After loading the scene, the user is given an introduction to the scene and how to use the AR to trigger questions (Fig. 28). Pointing the camera at any of the six accompanying AR markers will trigger an AR questionmark to appear on the marker. The markers are six of the virus illustrations from the pupils of Anderston primary school. Tapping the questionmark on the screen will trigger a trivia question to appear. There is a mix of 'true or false' questions and multiple choice questions. Selecting the wrong answer deactivates that selection and a panel appears prompting the user choose another answer. Selecting the correct answer triggers an animation and a continue button to appear. Pressing the continue button closes the question panel.

Figure 28 – Introduction panel for the Trivia scene.

Figure 29– Question from the Trivia scene showing the question panel as it first appears (left) and when the correct answer is selected (right).

The user can go through the questions in any order. Completing all six questions correctly triggers a panel which congratulates the user (Fig. 30). They are able to either restart and replay the scene or return to the index scene.

Figure 30 – End panel of the Trivia scene that congratulates the user and gives them the option of replaying the scene or returning to the Index scene.

3.5 Big vs Small Scene

Big vs Small is a short quiz within the application. As part of the larger project, the scientists on the team spent a week with the pupils presenting activities that described immune responses to viruses. A key concept that they struggled to explain was just how small viruses are. They wanted a visually stimulating method to describe this concept and therefore we incorporated the 'Big/Small' quiz into the application.

The user is asked how many viruses they think can fit inside a cell, a midge or the Glasgow Hydro. The user is given three options for each of the questions. By selecting the wrong answer, the same as in the trivia scene, a panel appears and the user is prompted to select another answer (Fig. 31). By selecting the correct answer, an animation plays of the lung character dancing, and the user can continue on to the next question (Fig. 32).

Figure 31 – Big vs Small question panel showing the visual indication that an incorrect answer was selected and a panel that prompts the user to select another answer.

Figure 32– Big vs Small question where the correct answer has been selected and a celebratory animation appears in the bottom left-hand corner.

After completing all the questions, the user is congratulated and given the choice of going through the questions again or returning to the index scene (Fig. 33).

Figure 33 – End panel from the Big vs Small scene which congratulates the user and allows them to return to the index scene.

3.6 Ending

On completion of the AR animation, the Trivia scene or Big vs Small scene, the user is rewarded with a stamp on the index scene as visual representation of the user having completed it. The text at the end of each scene also hints to the greater ending of being an expert immunologist.

Figure 34– Certificate awarded to the user (Orla) for completing the Learn in AR scene, the Trivia scene and the Big vs Small scene.

Once the user has completed all three of these scenes, the user is rewarded with a certificate (Fig. 34). This certificate proclaims the user as an expert immunologist.

The certificate is personalisesd with the user's name which they inputted at the beginning of the application. The certificate can be accessed using a 'certificate' button which is now available on the index scene (Fig. 35). The user is also able to reset their progress from this screen using the reset button. When this button is pressed, the certificate is no longer accessible, and the stamps on the index scene disappear. The user must play through the application again to access the certificate again.

Figure 35– Index scene with the three stamps the user has been awarded for completing the corresponding scenes, and a certificate button now active on the scene.

3.7 Cell Defender

This is the game scene of the application. It is not required to be completed to access the certificate. Starting the scene, the user is introduced to the game and instructed how to play (Fig. 36). Pressing the start button closes the panel and begins the game.

Figure 36– Introduction panel to Cell Defender game scene.

Viruses enter the lungs at the top of the screen and circle around an immune cell in the centre of each lung. At a random time the virus will move towards the immune cell. The user must move the antibody on the immune cell to "catch" the virus. The user controls the antibody using two on-screen joy-sticks (Fig. 37). Each virus that is caught increases the score. After scoring 6 points the immune cells develop another antibody, symbolising the developing of immunity after exposure to a virus. However, an increase number of viruses coming into the lungs also occurs.

Figure 37– The Cell Defender Game. The score and timer are shown in the top right-hand corner. The pause button and mute button in the top left-hand corner. Two joysticks are on either side of the screen which control the Antibody's rotation around the blue centre sprites.

The game has a 90 second timer after which the game ends. A panel appears congratulating the user and showing the final score (Fig. 38). The user is given the option to replay or to return to the index scene.

Figure 38 – Cell Defender game end panel which congratulates the user, shows their final score and allows them to either return to the Index scene or replay the game.

The user is able to pause the game at any time using a button in the top right-hand corner of the screen. Pausing the game triggers a panel (Fig. 39) which gives the user an option to restart the game or return to the index scene.

Figure 39 – Cell Defender game scene pause panel which allows the user to resume or restart the game, or return to the Index scene.

4 Evaluation

We scheduled a follow up meeting with the participating pupils from Anderston Primry School to ask them to provide feedback on the application. To achieve this, we provided them with two custom questionnaires (see Appendix 2), one to be filled in before they accessed the application to measure their expectations and one to be completed after they had a chance to play with the application. The experiment was setup under the supervision of the teacher, and the questionnaires were sent back to the researchers afterwards. An online meeting was then organised to discuss their responses with the pupils.

Of the 16 pupils who completed the pre-questionnaire, 94% (15/16) thought that application would be fun, and they all thought they would learn from the application. Most (75%; 12/16) thought that it would be easy to use and the majority thought that their drawing would be included (94%; 15/16).

The post-questionnaire was completed by only 12 pupils. A majority (83%; 10/12) gave the application a score of 3 or 4 out of a max score of 4 for how much they enjoyed using the application. All 12 pupils reported that they had learnt something from the application, the majority found it someway easy/or easy to use (75%; 9/12), and most agreed that their drawings had been included (92%; 11/12).

Some pupils added some helpful free text to the post-questionnaire. Most of these comments were positive (83%; 10/12) and covered their involvement, learning, and how easy the application was to use. The comments included:

"(it was good) That it includes everyone's ideas, voices and drawings"

"The app made me feel happy because my drawing was included in one of the games"

"I learned how the immune system works to fight infections and viruses"

"The app is very easy to use"

Of the two negative comments, one thought that some of the questions to test their knowledge were too easy and one pupil found the Augmented Reality in the application challenging.

When the researchers met with the pupils online, they seemed enthusiastic about the application. The teacher also commented positively on the App and the ease that most pupils had found in using it. Anecdotally, the Cell Defender game had proved particularly popular leading the pupils to spend more time using the application.

The pupils highlighted some technical problems with the application that have required a refinement development iteration to be completed before any deployment on Android/iOS store to be performed. These included problems with the triggers for the AR and in re-setting the Cell Defender game.

5 Discussion

The methodology described in this chapter produced an educational application with AR animation, a game and two quizzes. This application was positively received by the pupils who participated in the co-design workshop and was an effective learning tool to teach them how their body reacts to defend itself against a respiratory virus attack.

By using the pupil's outputs of the co-design workshop, the pupils gained a sense of ownership of the application that enhanced their engagement with it. Our results agree with

Fuchsova and Korenova (2019) who suggests that not only understanding of scientific concepts is increased but also that the pupils creativity is supported.

The use of AR within the application was intended to further increase understanding and engagement with the learning content, as suggested by Connaghan et al. (2019). Further research with our application could quantify knowledge gain and retention after pupils use the application, and could focus on the use of AR, which delivers the main portion of the educational content. Yilmaz et al. (2022) created a volcabulory learning application for children that used AR. Their results suggested AR increased the children's enjoyment of the application, which agrees with Giannoakas (2013). Our research adds to this literature, as the pupils feedback suggests they enjoyed the application, most found it easy to use and they learnt from the application (again, the main bulk of the educational content is taught through AR).

A game was included to increase the time spent using the application, and from the results of the evaluation, the game was very popular and greatly played by the pupils. This is beneficial as the game is based off of the taught content within the application. Further developments could be made to use the games popularity and increase the educational content within it.

All of the artwork within the application was based on the artwork from the co-design workshop, including the AR markers. The triggering of the AR over the AR markers were made less stable depending on lighting conditions (Blom, 2018). To counter this challenge, more stable markers could have been developed following the guidelines such as those from Vuforia, a commercial AR platform (https://library.vuforia.com/objects/best-practices-designing-and-developing-image-based-targets). Additionally, more instructions could be added to the introduction scenes of both AR scenes that tell the user what the optimal conditions are.

For both the AR scenes, there were issues making the gameobjects appear in AR and also animate. The script component added to the AR Session Origin controlled when the gameobject was set active. For the Learn in AR scene, the tracking state had to be tracking for the AR to appear and run smoothly. If instead the tracking state was limited, the AR would appear but not animate. This was an issue for an AR animation. Therefore if the tracking state was limited, the cube gameobject (parent gameobject to the animated sequences) was set as not active.

However, in the Trivia scene, animating was not the problem, but multiple AR gameobjects appearing on the same marker at once rather than one single AR gameobject for one marker. This issue was solved by allowing the tracked imaged state as limited to set the gameobject active.

The game was added to increase time spent on the application and add a fun, interactive, timed challenge. At the end of the game, the user is told their final score and given the option to replay it. Originally, this replay button simply reloaded the game scene. However, this did not reset the score or the timer, making it so the user could keep playing for as long as they wanted and keep scoring more and more points without ending the game. This was fixed by having the replay button additionally set the score back to zero and set the timer to 90 seconds again before reloading the scene.

The RotateAround() function was greatly used for the movement of both the user Antibody and the “enemy” sprites. This was chosen for the “enemy” sprites so there was more control over when the sprite movement changes from rotating around the centre sprite to moving towards the centre sprite. The alternative was using an animation of the “enemy” sprite circling the centre sprite. There were issues making the animation end at random times before moving towards the centre sprite. The RotateAround() function was the simplest solution.

The Unity project and resulting application is very large and this can cause issues like the application crashing. Each sprite was imported individually, which is an issue when there is a long animation. Compiling the sprites into sprite-sheets would greatly reduce the size of the application and Unity project files, and minimise the application crashing.

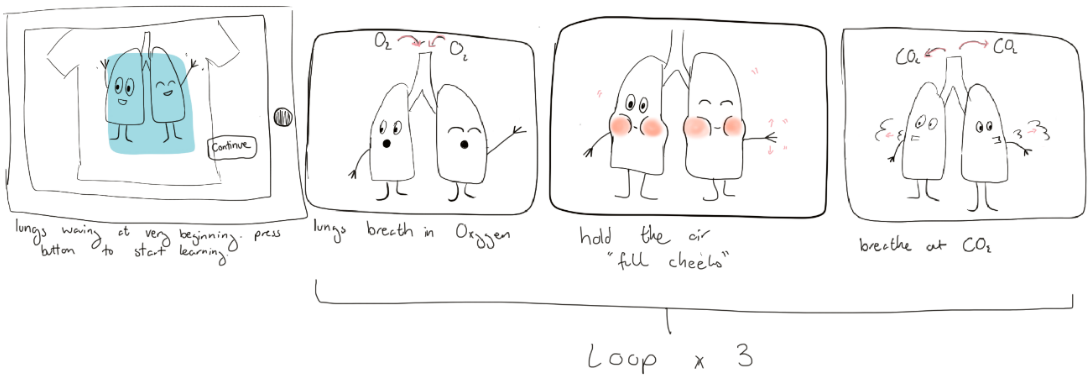
6 Conclusion

The Co-IMMUNicate application is an integral part of the larger Co-IMMUNicate project. It has provided the researchers with an easy tool to introduce quickly the topic of immunity to respiratory viruses to each P6/7 class at Anderston Primary with which they work. This enables the researchers to introduce new material each year that expands the knowledge and understanding of the pupils and the teachers involved in the project. The application is also a fantastic tool to increase engagement at festivals and workshops that the team attend. For example, the team, presented an activity at the 2021 Glasgow Science Festival and were joined by some of the school teachers and pupils who has been involved in designing the application. The pupils introduced the application to festival attendees, often using the quizzes to test the knowledge of participants. The sense of pride and ownership of the application which the pupils had greatly enhanced the team's ability to communicate the project's key messages. Finally, the team aim to launch the application through Google Play and the application store, this will greatly increase the impact and reach of the project, encouraging children across the globe to learn more about immunity to respiratory infections and have a positive approach to immunological research.

Appendix 1

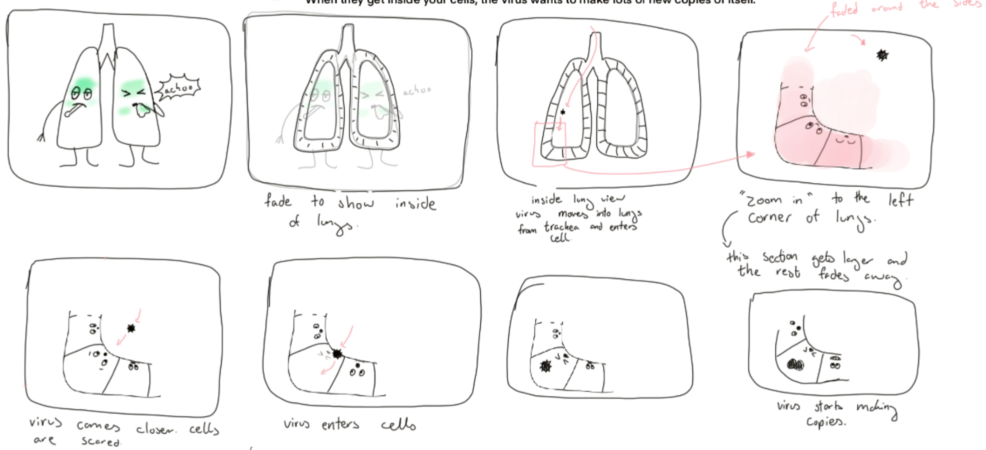
Appendix 1 shows the storyboard created for the Learn in AR animation along with the script.

1 Your lungs are really important - they are working hard to make sure you can breathe in the oxygen you need and breathe out carbon dioxide.

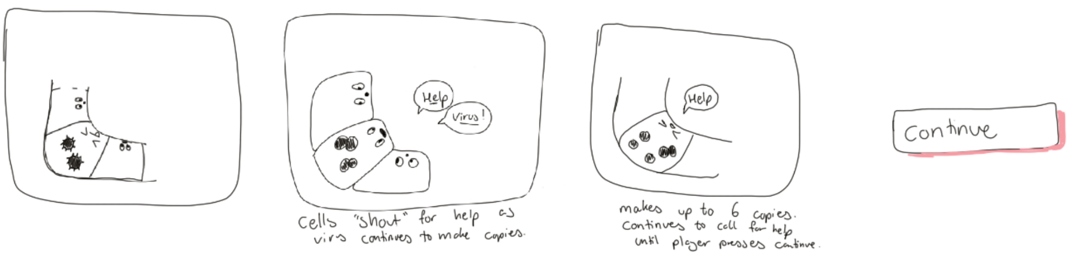


2 When you breathe in you might also inhale tiny viruses. Some of these viruses, like flu or the COVID virus, can make you ill.

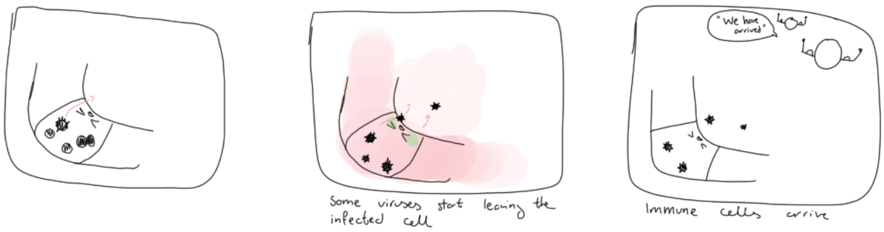
3 When they get inside your cells, the virus wants to make lots of new copies of itself.



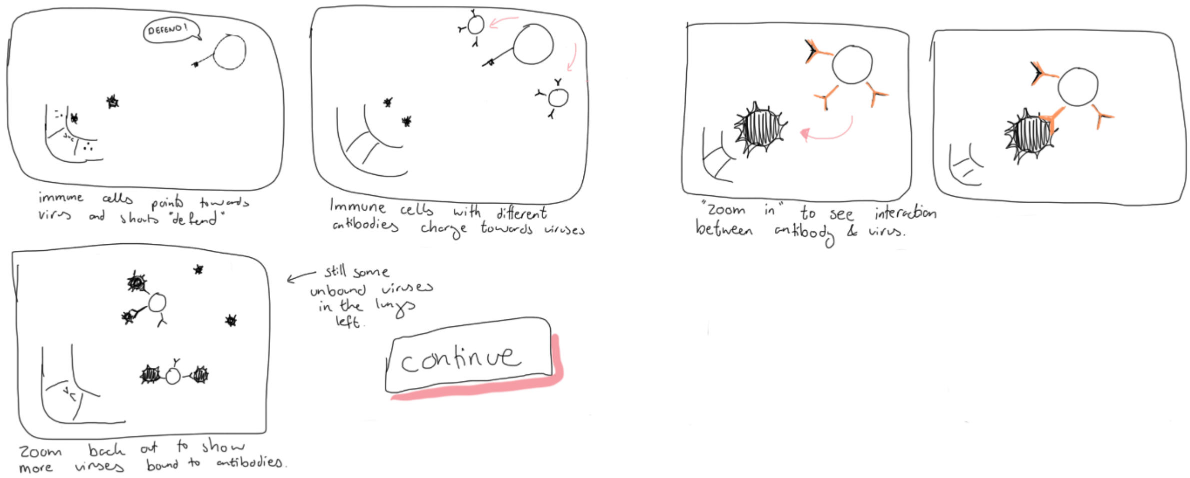
4 But when it does this, your cells shout out and tell their neighbours that a viral attack is happening.



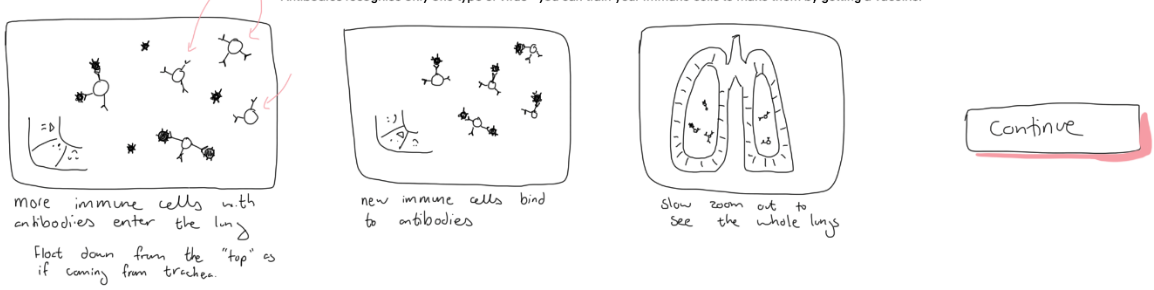
Your immune cells are called into the lung to help stop the virus.



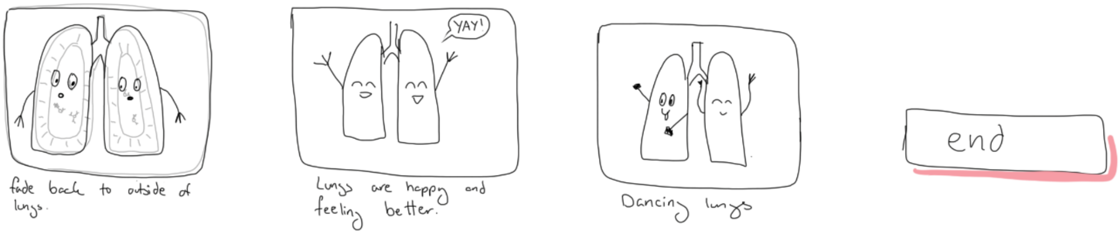
Some of your immune cells make antibodies. These bing to the virus and stop them from being able to infect any more of your cells



Antibodies recognise only one type of virus - you can train your immune cells to make them by getting a vaccine.



The antibodies your immune cells make after an infection or a vaccine can be found in your nose, throat and lung. They can stop any new viruses of that type from infecting you and making you ill!



Appendix 2

App evaluation

Questions for the pupils:

Before they get the App and before the get the voice over powerpoint if possible

1. Do you think the app will

Be boring:	Yes	No
Be fun:	Yes	No
Teach you something:	Yes	No
Be easy to use:	Yes	No
Be difficult to use:	Yes	No

2. Do you think your drawings and ideas will be used in the App:

Yes
No

After they have had the app

1.
How did the App make to feel?

2. How easy was the App to use?

3. Did you learn about viruses from the App?

No – I already knew all the things about viruses in the App
Yes – I learnt a little more about viruses than I already knew
Yes – I learnt a lot from the App about viruses

4. Did you learn about how your immune system helps you when you have a virus?

No – I already knew all the things in the App
Yes – I learnt a little more than I already knew
Yes – I learnt a lot from the App

5. Do you think your drawings and ideas are included in the App?

Yes/No

6. What is your favourite thing about the App?

Free text

7. What did you not like about the App?

Free text

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