**What Not to Do With PPE: A Digital Application to Raise Awareness of proper PPE Protocol**

# Abstract

With an abrupt rise in the use of personal protective equipment (PPE) by healthcare professionals (HCP) as a prime infection control strategy in the wake of the COVID-19 pandemic, comes the unfortunate increase in its misuse. The justification for this failure to follow proper PPE protocol in order to prevent self-contamination and transmission can be attributed to both a lack of formal training and guidance and, now, atrophy of infrequently used skills, with many senior professionals demonstrating a lack of proficiency despite years of service. Previous research shows current written and illustrated instructional material depicting PPE guidelines are abundant but does not provide an answer to the best way to target violations in protocol and better instruct those that are providing prehospital emergency healthcare.

In this chapter, we aim to address the gap in paramedic-specific research into PPE protocol and provide an educational, digital tool to work alongside the current guidelines, using cognitive load theory (CLT) as a design strategy. The use of 3D, interactive animations depicting incorrect protocol and its potential contamination consequences in a device-based application could engage HCPs in a more effective way, thus increasing protection and decreasing transmission. This chapter describes the methodology behind the design and development behind such an application for the Scottish Ambulance Service (SAS) and provides the relevant materials needed to carry out user testing and evaluation once participants have been recruited.

# 1 Introduction

With the number of COVID-19 cases, as of Jan 2021, having reached 102 million worldwide (Worldometer, 2021), the need for adequate protection against viruses for those treating infectious patients has never been more critical. The frequent opportunities for unrecognised transmission of pathogens in conjunction with the close contact of vulnerable individuals in the healthcare community means that personal protective equipment (PPE) is a fundamental layer of protection to both health care professionals (HCP) and the people around them. In order to optimise the use of PPE and ensure safety standards are met, there should be training and guidance upon proper use of equipment; however, there is a distinct focus more on the ‘do’s’ and less on the ‘don’ts’, where conscious and subconscious slips whilst wearing PPE can be harmful and potentially fatal.

A rise in National Health Service (NHS) workers having to source their own makeshift masks, scrubs and visors due to shortages through the official NHS channels (British Medical Association, 2020) has highlighted the importance that anything being used in the context of infection control must be done as efficiently as possible. Furthermore, statistics showing one in five ambulance staff off sick with COVID-19-related illness (BBC News, 2020) and excess deaths among frontline NHS workers has highlighted the devastating consequence of PPE shortages, particularly in light of new evidence that the level of viral load, or exposure to the virus, is directly proportional to severity of symptoms (Liu et al., 2020). It therefore falls upon the absolute compliance of NHS workers to ensure they are doing the best with what they have. This is crucial when coupled with volunteering of retired NHS HCP, where it has been suggested that older and more experienced professionals use PPE less frequently and thus less optimally (Huertas et al., 2019).

The current guidelines offered by public health organisations in the UK consist of traditional material such as infographics and illustrative videos alongside written information. Studies have shown that when the direct consequences of PPE misuse, specifically cross-contamination, are not clearly outlined within guidelines, they are not as effective (Katanami et al., 2018). In a recent systematic review, it was revealed that computer simulation or video material leads to fewer errors in PPE use compared with traditional methods (Verbeek et al., 2020). The focus on what to do with the equipment, instead of presenting specific violations against PPE protocol, is also an important aspect to consider; these violations, such as touching a face mask whilst it is on, are often subconscious but can detrimentally lead to both self-contamination and cross-contamination (Zamora et al., 2006), and therefore should be targeted in training procedures.

Although some of the publications referred to in this review relate to COVID-19-specific PPE use, the principles still apply to more routine PPE use. The development of this application could therefore be useful in a wider and more general context of healthcare provision even after the current outbreak has passed.

## 2 PPE

PPE is designed for two main purposes: to prevent HCP spreading infection from one patient to another, and to prevent HCP from becoming ill with the infection themselves. Due to the microscopic size of infectious agents, their contamination and transmission goes unrecognised unless an individual obtains a positive virology test or displays symptoms, which may be days after infection, during which they may have spread the infection to both surfaces and people. Even with PPE, HCP are still vulnerable to contamination if it is not removed properly (Fischer et al., 2014), therefore, proper training and compliance to PPE guidelines ensure HCP are safe and there is no increase in transmission of pathogens.

The definition of PPE can differ depending on the context and the level required but it most commonly involves items such as masks, eye protection, gloves and gowns. Figure 1 displays the recommended equipment for ambulance staff; this guidance was provided by the government in association with Health Protection Scotland, Public Health Wales, Public Health Agency and the NHS (Public Health England, 2020). Aerosol generating procedures (AGPs), such as intubation and tracheotomy procedures, give rise to the highest possible risk of infection of respiratory viruses (Health Protection Scotland, 2020), where the use of enhanced shielding and fluid-protective equipment is necessary. Figure 2 displays the current donning and doffing protocol from Public Health England (PHE).

### 2.1 PPE Education: Training and Guidance

#### 2.1.1 Training on proper PPE use

Although the actions of donning and doffing of PPE appear straightforward, formal training can help minimise error and risk to both HCP and patient. In order to determine the level of education and training HCP receive on the proper use of PPE, a search on Google Scholar was carried out using a wide range of terms (and combinations of) such as: medical, education, PPE, training, UK. Though the search resulted in upwards of 10,000 publications, many were irrelevant to the search (the majority only applied to the US), suggesting that formal training in PPE use was not a subject typically taught during medical education. A study carried out in the UK about medical students’ knowledge of infection control revealed that 58% of 156 students did not know how to correctly use alcoholic hand gel and 35% were unaware of correct glove use (Mann and Wood, 2006); this followed the evidence that some students had only been taught hand hygiene informally or not at all. One result gave an insight into HCP’s knowledge of PPE protocol: a hospital in the North-West of the UK carried out a 24-hour pandemic simulation exercise in a single respiratory medical ward to pinpoint operational PPE issues (Phin et al., 2009). Although this study’s aim was mainly to identify the quantity of equipment used in the context of a pandemic, it provided an interesting look into which specific aspects of PPE use HCP felt uncertain or uncomfortable about, such as donning, doffing, and the safe use of PPE. Even in the wake of the COVID-19 pandemic, a survey carried out on 714 Foundation doctors on support and training received found that 74% had received no formal training with regard to infection control practises (Blackburn et al., 2020). In a prospective study, 6 months after extensive PPE training, only 14% of paramedics were able to don and doff PPE without committing a critical error – one deemed to potentially result in major self-contamination (Northington et al., 2007). When many of the skills required to use PPE safely are not employed frequently, atrophy occurs.

A recent study into this donning and doffing training during medical school in the US showed that, in a survey was carried out of 222 HCP, only 41% received proper training in PPE use, with no medical school requiring the HCP to demonstrate their proficiency in PPE use before furthering their education (John et al., 2017). Less than 40% of participants chose the correct order whilst donning and doffing based on Centers for Disease Control and Prevention (CDC) recommended protocol, suggesting there may be a significant problem with insufficient PPE training during medical education. A study carried out in the UK about medical students’ knowledge of infection control revealed that 58% of 156 students did not know how to correctly use alcoholic hand gel and 35% were unaware of correct glove use (Mann and Wood, 2006); this followed the evidence that some students had only been taught hand hygiene informally or not at all.

Additionally, there has been a suggestion that the invisible aspect of contamination and lack of immediate visual feedback can contribute to reduced retention in proper PPE protocol (Tomas et al., 2016). The use of fluorescent lotion contamination during doffing of PPE, whereby UV markers give strong cross-contamination feedback to the user enabling a better understanding of pathogen transmission routes, has proved to be an effective educational training intervention (Tomas et al., 2015). It was said that the very visual demonstration of the scope of contamination facilitated real-time discussions about the subject and reinforced the need proper use of PPE (Poller et al., 2018). A recent study about contamination within veterinary practises and a possible training intervention using simulation demonstrate the use of a monochromatic, 3-dimensional (3D) animation with additional coloured layers. (Macdonald et al., 2019). Figure 3 and Figure 4 show the veterinary environment with and without a green layer showing where infection control measures are in place. Feedback from this development session suggested that the monochrome environment and high degree of fidelity in order to focus on risky behaviour was popular among practising veterinary surgeons. After using this training intervention, 92% of participants agreed to align their infection control behaviours with the behaviours shown in the animations.

#### 2.1.2 Guidance on proper PPE use

The current publications which demonstrate proper PPE use around the world are vast and somewhat overwhelming. A rapid scoping search using the Google platform for ‘personal protective equipment guidance NHS Scotland’ yields 1,480,000 results (as of 23rd May 2020). Understandably, most of the recent results are specific to COVID-19 or SARS-CoV which lead to varying types of governmental guidance on the donning and doffing of PPE including, but not limited to, detailed documents, simple illustrations, and videos. The Health Protection Scotland website has links to various downloadable posters depending on the context of PPE use and a 6-minute long video on the correct order of donning, doffing and disposal of PPE (Health Protection Scotland, 2020b). The website also directs the user to PHE’s guidance on COVID-19 (Public Health England, 2020). This consists of specific instructions such as which equipment to use in which context and again, the correct order for donning and doffing. However, any references to what HCP should make sure they do *not* do with PPE are few and far between - the importance of preventing infection control breaches whilst the equipment is in use, such as touching the exterior or the mask or dangling it around the neck, is mentioned briefly but not enough significance is placed upon this potential misuse.

Following the evidence that research around the behaviour of paramedics and their use and misuse of PPE is lacking, there appears to be a gap in evidence-based ambulance-specific guidance too. Written material for PPE use can be found on PHE’s website easily, butt official PPE guidance specifically for paramedics in Scotland in the form of illustrated material or diagrams were not found with ease.

### 2.2 What *not* to do with PPE

The repercussions following a lack of formal training in PPE protocol is reflected in many observational studies looking into infection control behaviour. A study investigating this found that of 325 HCP observations over a nine-month period, 283 violations capable of causing self-contamination or transmission of infection occurred (Krein et al., 2018). These deviations from protocol ranged from common scenarios such as entering a patient room without PPE on, to reflexive actions such as pushing glasses higher up on the face. Failure to use PPE correctly is well documented within the literature, but the repercussions surrounding these failures are not as well addressed. In addition, research in this area has highlighted a significant gap in research surrounding ambulance staff, and even more specifically, in the UK; much of the literature focuses on HCP within hospitals and fails to address the workers providing pre-hospital emergency care.

It has been suggested that probably the largest risk of infection occurs when HCP incorrectly remove PPE, carelessly or in the wrong sequence, which leads to self-contamination (Tomas et al., 2015); this suggestion has been supported by a number of studies, with one finding more than half of HCP removed their PPE incorrectly (Zellmer et al., 2015) and a further study that found 85.7% of subjects, emergency responders in the US, committed a critical error during doffing of equipment (Northington et al., 2007). Another common problem involves patient-care HCP carrying out tasks such as touching a computer screen whilst still gloved or, vice versa, contact with items within the patient environment without gloves on (Clock et al., 2010). In the Krein study, a similar problem where subconscious HCP behaviour, such as the tucking of hair behind the ear or touching of eyeglasses whilst still wearing gloves, was observed.

## 2.3 Cognitive load theory

To provide a framework for the application specific to the design of instructions, cognitive load theory (CLT) will be used; it has been in use since the 1980s, built upon recognised models of memory to optimise the way we process and learn information into long-term memory (Chandler and Sweller, 1991). CLT proposes three types of cognitive load that affect working memory (WM): (1) intrinsic load, the fundamental difficulty of instruction which is immutable by intervention but essential to the task and usually determined by prior knowledge of the topic; (2) extraneous load, the load attributed to presentation of information, an aspect under the control of instructional designers; and (3) germane load, the aspects of design that deliberately use cognitive strategies to aid learning and the development of ‘schemas’. CLT suggests that if the overall cognitive load exceeds WM capacity, learning and successful completion of the activity is impaired. When designing instructions, techniques should be put in place to manage intrinsic load, decrease extraneous load, and assign unused WM to germane load and thus, optimise performance (Alloway et al., 2009). Later research into CLT has also shown that techniques designed in order to help novice learners in a specific expertise, such as decreasing this extraneous load, has an opposite effect on experts, those with significant prior knowledge and schemas, and can even result in worse performance, a phenomenon known as the “expertise-reversal effect” (van Merriënboer and Sweller, 2010). To combat this phenomenon, several strategies have been suggested: (1) integrated to nonintegrated strategy, whereby, for example, surgical procedures are shown to medical students using both integrated pictures and text, but shown to experienced surgeons with just pictures; (2) fading guidance strategy, where guidance and feedback is gradually reduced as the learner becomes more experienced; and (3) dual- to single- mode strategy, where students are given spoken explanations when studying an animation, but the sound is switched off for experienced students.

The nature of medical expertise means the learner has to build a complex long-term memory system over the course of their education and professional life, so CLT has relevance to medical education in particular. When many professional tasks in the field require the integration of multiple categories of knowledge and skills at varying degrees, it may inflict a cognitive load on the learner that exceeds their WM capacity (Young et al., 2014). It has been suggested that often learners are not able to transfer what they have learnt during education to application within the workplace, where the WM cannot retrieve and combine fragmented long-term memories together under common work pressures (Konkola et al., 2007); this is particularly relevant within the field of prehospital emergency care, whereby paramedics are forced to make decisions quickly and efficiently to provide a certain level of care and potentially save lives. To combat this, CLT has generated multiple cognitive load principles, or ‘effects’, which can be applied to the medical education context (van Merriënboer and Sweller, 2010).

When it comes to managing intrinsic load, empirical evidence has been provided to support a model based on CLT called ‘Simulation Fidelity’, which works upon the idea that progressive training with varying degrees of realism, from low to mid to high fidelity, would be an effective way to transition medical students’ into clinical medicine (Brydges et al., 2010). Researchers found that groups of subjects learning intravenous catheterisation in the process of either progressive learning, high fidelity, or low fidelity, the low fidelity group performed the worst in terms of clinical and technical skills. There is also evidence that advanced students benefit more from high fidelity training (Alessi, 1988), an important aspect to take into account when the users for the proposed application will be experienced paramedics who are no longer students. Although in the current research a “high fidelity” refers to simulation, which would not be possible in the case of this research, a reasonable bridge in the gap between basic, paper-based instruction and simulation could be an interactive, animated, 3D application. This would force the learner to retrieve existing long-term memories and scheme relevant to the topic and consolidate this information further.

The instructions do not consist of complex theories, but the design of instructions (Figure 5) is often cluttered in a way that might impose unnecessary demands on the learner leading to increased extraneous load. Mayer and Moreno (2003) have proposed various different methods to control cognitive load determined by the different systems used by the brain to process pictorial and verbal material. (1) Weeding, whereby interesting embellishments, such as background music, that increase the amount of incidental processing, ie. processing that is not essential to the task at hand, is suggested to reduce unnecessary extraneous load; (2) Aligning: a seemingly trivial aspect of design that should be considered due to significant effects on learning is the alignment and placement of text within the scene - the most optimal way is to have text next to the elements it is describing to, again, reduce incidental processing through scanning the graphic to find text; and (3) Signalling: providing visual cues on how to process the information presented such as arrows. Goal-free principle is also a technique suggested to be one of the most effective for managing extraneous load, and it allows learners to explore the information presented to them without being blocked by a question to answer, thereby giving the learner more autonomy (Mayer and Moreno, 2010). Learner pace control is another method suggested to allow the learner to adapt the app to their own individual cognitive needs by providing them with play, replay, pause and continue controls. This aims to combat the issue in some animations where important information and critical objects are transient, meaning some cognitive load is taken up remembering previous aspects of the animation (Hasler et al., 2007).

## 2.4 Conclusion

It is clear from the current literature that there are significant gaps in research, including both PPE-use behaviour of paramedics and how guidance might best be targeted to HCP that are providing emergency healthcare. In addition to this, it is clear the misuse of PPE is more common than might be expected, a problem leading to increased contamination events which might be attributed to improper training, incorrect technique and a lack of guidance.

In this thesis, these highlighted gaps will therefore be addressed by developing an educational, digital application for paramedics in order to raise awareness of the importance of PPE and tackle problems regarding equipment misuse, which can have potentially detrimental effects in both delivery of prehospital emergency care and self-contamination. This application will not be used solely for training purposes, but more as an additional educational tool to complement the current traditional material provided by the relevant bodies for HCP to familiarise and strengthen the knowledge they already have already acquired on PPE protocol.

To gather relevant information for the application, a co-design process will be carried out by involving paramedics from the SAS to ascertain the most important issues surrounding PPE use. From these common problems, the information will be integrated into the application using CLT as the basis of the game design in the form of PPE use animations. Various efforts to reduce cognitive load will be used, including those suggested by Mayer and Moreno, including player pace control, weeding, and goal-free principle. Expertise-reversal effect will also be taken into account: due to our target audience being established paramedics, therefore ‘experts’ in their field, the app design will employ the three van Merriënboer and Sweller strategies as outlined in Section 2.2. Instant visual feedback in the form of a semi-transparent coloured layer overlaid PPE in the monochromatic environment, will also be included, following evidence this may aid learning and help develop schemas.

Despite guidance and some training already in place for HCP, this project could improve the efficacy of current guidance and potentially contribute a unique option for training interventions, with the overall aim to increase compliance and reduce cross-contamination of infectious agents.

# 3 Methods and Materials

## 3.1 Methods

It is clear from literature research that (1) proper use of PPEs and this behaviour specifically within the emergency healthcare community is less widely understood and (2) the current educational tools used in healthcare settings fail to address incorrect and potentially harmful behaviours that may arise both consciously and subconsciously while using PPE. Therefore, it was decided that the app would aim to target this by using interactive 3D animations to complement existing material.

The narrative of the app was developed: the user will be faced with three different situations in the form of an 3D animation, each presenting a different type of PPE protocol violation, such as touching the patient without gloves on. The user can interact with the environment and must then select the area, ie. the gloves, with the problem. They are able to toggle a semi-transparent layer showing where infection transmission could occur in this case, with an information box reminding the user of the correct protocol in this situation.

#### 3.2 Digital Design

For the user interface (UI) design inspiration, a search for e-healthcare and medical app design was conducted on Pinterest, Google Images and Dribbble. It was immediately clear from the results that the running theme of most apps within this industry had a colour palette consisting of calming blues, greens and pastels and very clean UI assets to ensure clear comprehension from the user while still remaining attractive. As the focus on many of these apps is to convey important information without the need for decorative embellishments, which is also the case for this research, it was decided that the UI design would maintain a clean and cohesive theme incorporating similar calming colours from a colour palette of blue, greys, and a contrasting red for the transmission layer (Figure 6). The blues used in the app’s colour palette would be similar hues to the NHS and SAS logos to maintain cohesion. The app’s unique user interface was designed on Adobe Illustrator. The buttons, such as a the ‘home’ button, benefitted from simple outlines in order to be consistent with generic designs used in other apps in order for the user to navigate easily.

NASA’s guidance on designing flightdeck procedures and checklists was consulted, which followed existing literature on checklists, not limited to aviation, where following the incorrect steps is most detrimental (Barshi et al., 2016). The design of these steps follows strict rules, such as the format of text and font use, elements of which were taken into account when designing the app’s UI.

#### 3.3 3D Model Development

##### 3.3.1 Identification of PPE Violations

It was important that the animations of the chosen PPE violations were accurate in terms of importance in order for the app to be a relevant addition to current guidelines. A list of common scenarios where violations might occur were identified from the literature (Krein et al., 2018) and sent to Dr. David Fitzpatrick in order to heuristically rank them from most risky to least risky. The top three were identified as follows: (1) Touching/repositioning the front of mask with/without gloves on while carrying out procedure; (2) Using a mobile device with contaminated gloves still on; and (3) Removing/putting goggles on with gloves on. This list was taken into account, in addition to the need for the animations to look realistic given the context and long enough for the user to identify the violations, when deciding the definitive animation sequences for the app. The identified ‘problems’ to be in the app are as follows, however given time constraints, it was decided that the first two would be essential and the third if time allowed:

1. **Scenario 1 (Contamination of face mask):** Scene shows a paramedic using his stethoscope on a patient lying on a stretcher. Mid procedure, the paramedic adjusts the front of his face mask before continuing on.
	1. The user will have to select the mask, or the hand used to touch the mask.
2. **Scenario 2 (Contamination of phone):** Scene shows a paramedic sitting down in the ambulance. They reach into their pocket to pick up a mobile phone and proceeds to use it, with gloved hands. They then put the phone up to their ear as if on the phone.
	1. The user will have to select the mobile phone or the gloved hands as the ‘problem area’.
3. **Scenario 3 (Contamination of goggles):** Scene shows paramedic entering the ambulance and proceeds to don eye protection, whilst already wearing gloves.
	1. As this is the incorrect donning order, the user will have to select the eye protection and gloved hands as the ‘problem area’.

##### 3.3.2 Modelling

Various 3D models for the scenes were required: a main avatar as the paramedic to demonstrate the various PPE misuse scenarios, equipment to be used incorrectly, a patient, the ambulance and the objects within the ambulance environment. As the rigging and animation of the avatars would take up a significant amount of time, it was decided that the simpler models, e.g. components of the ambulance such as cabinets, would be developed and the rest purchased from a 3D model marketplace.

The 3D models were developed in Maya 2019. Initially, the total polygon count within the ambulance environment was approximately 70,000+ - the majority of these polys were from the imported stretcher asset and the ambulance skeleton itself. To combat this, each model was split into its individual components using the ‘Separate’ tool and, using the ‘Reduce’ tool, the polycount was reduced to its lowest possible level while maintaining the original shape. Given that the main focus within the animations is the paramedic and to reduce cognitive load, it was not as important for the models within the ambulance environment to be detailed, only to provide some context. Using this same method for all models within the ambulance environment, the total poly count was reduced to 27,441. This reduced poly count allowed for more detail when it came to the paramedic, which had a high poly count of 30k+, and ensured system performance was not compromised once imported into the Unity engine.

##### 3.3.3 Animation

For all three animations outlined in 3.3.1, a general workflow was developed. It was decided that the paramedic model would be isolated and animated in Maya, then placed into the scene within Unity. The workflow consisted of first blocking out and keyframing the major poses (Figure 7, Figure 8) – for the Phone Contamination scenario, this involved the paramedic (1) sat down in an idle pose; (2) appearing to touch his phone as if keying in a phone number; and (3) talking on the phone. This is done by using the Rotation tool on the relevant joints on the character’s pre-rigged skeleton. Once these poses were keyed into the time editor, they were then refined into a smoother animation using the graph editor (Figure 9, Figure 10).

In order to animate the transfer of the phone in this scenario from the paramedic’s pocket to the paramedic’s phone, it was constrained using a Parent constraint twice, first to a locator in the paramedic’s pocket and then to a locator in the hand. In the attribute editor, only one of these constraints was on at any one time and animated to be switched between the two.

#### 3.4 App Development

In order to ensure the user’s experience made sense chronologically and ensure clarity before development of the app began, a schematic map of the scene flow was developed. Upon opening the app, the user begins with the main menu, followed by a scene with instructions to select a scenario of their choice. They are then taken to the 3D animation of this scenario, from which they must identify the area where there is a failure to follow PPE protocol. The user is then taken back to a menu to complete the other scenarios.

##### 3.4.1 User interface set-up

Within the UI of the animated scenes there is a control bar at the top of the screen, allowing the user to control the animation and return to the main menu or quit the app at any time while using it. This was done by having clickable replay and pause buttons on the left side, and clickable home and quit buttons on the right side.

In the spot test panel, it was decided that the rendered image would be the textured version of the paramedic model (Figure 11), in order to put what the user has seen in the monochrome animation into a more familiar context. The texture originally downloaded with the model was altered in Adobe Photoshop using a hue/saturation layer to change the paramedic’s scrubs from purple to green, used in the Scottish Ambulance Service. Using transparent buttons was deemed to be the most effective way in allowing the user to simply click on the problem areas. After clicking, the user sees the same image but with a semi-transparent, red layer to consolidate the information they have identified. This image, Figure 12, was modified in Photoshop using the Pen tool to outline the areas and filled in with a red brush with lower opacity.

##### 3.4.2 Interactive components

The interactive functions of the app were programmed using C# scripts as outlined by Table 3. The animations of the 3D models were controlled by the Animator Controller within Unity and then further controlled by the player using pace control UI buttons.

It was initially decided that the user would be presented with a ‘transmission toggle’ whereby they would be able to toggle a layer of visible contamination on the paramedic on and off, using Particle Systems. This was originally going to be done by using colliders on the contaminating objects to instantiate the particles, however it appeared to be quite taxing on the computer to keep instantiating whenever the user replayed the animation. It was therefore decided that the user would have the option at the end of the first animation to watch it again with the particle systems turned on or go straight through to the spot test if they had already identified the violation, thus giving the user complete control of their experience.

For the visible contamination animations, the particle systems were parented to the object they must follow. For example, one particle system representing contamination of the phone is parented to the hand holding the phone. Instead of using colliders, it was much simpler to delay the start of the particles for the areas, such as the phone, that became contaminated as a result of the violation in PPE protocol. Considering the outcomes of the AMRSim project and the visual implementation of contamination, it was decided that particle systems would be explored in place of projectors. It is hypothesised to provide a more reliable visualisation of contaminated areas on deformable meshes, as well as being more familiar to the user. In addition, it is expected that the slight blinking effect of the particles would bring further attention to this visualisation.

##### 3.4.3 Build to android

To build the app for an Android phone, the Android Studio SDK and JDK were installed and found within Unity preferences. The app was built on a Samsung S7 using the Android OS v8.0.0 system with an aspect ratio of 2560x1440.

# 4 Results: Application Development Outcome

The developed app is called ‘What Not to Do With PPE’ and the app icon shows two gloves in the same style as the rest of the UI, designed in Adobe Photoshop.

### 4.1 Main Menu

The first initial scene is the main menu or the ‘landing page’ of the app (Figure 13). It displays an ambulance with flashing sirens on a looping animation, the title of the app, and the play button. It also includes the logos for GSA and University of Glasgow. The font used here and throughout the entire app is ‘Axiforma’, externally sourced from the website Fontsfree.pro. The play button takes the user through to the Instructions scene.

### 4.2 Instructions

The second scene gives the user a brief overview of what the app will consist of and instructions on how to control the animation (Figure 14). As some of the buttons may be difficult to understand at face value, such as the spot test button and the button to watch the animation with a layer of visible contamination, they were explained in this section too. The user is then directed to the Scenario Selection scene via a button below the instructions panel.

### 4.3 Scenario Selection

The scenario selection presents the user with two options – scenario 1 or scenario 2, each represented by a virus icon (Figure 15). Initially, these icons were to represent the type of PPE misused, such as gloves, but as the user has to spot this in the following scenario, it was decided that a simple numbering system would work better to not give the user an idea of what is to come in the animation. The user also has the option to navigate back to the main menu or exit the app in this scene.

### 4.4 Scenario 1: Phone contamination

When the user selects the first scenario, they are taken to the first animation, showing the paramedic using his phone in the ambulance (Figure 16). The animation plays immediately as the scene loads and the user is able to control it by pausing and replaying or using the camera view panel to look at the animation from a birdseye view, from the side, or back to the front view. As there is no visible contamination in this scene, this is intended for users that may be well-versed in PPE protocol and recognise the misuse of PPE easily. After the animation has ended, the user has the option to either go through to the spot test straight away or watch the animation again with a visible layer of contamination (Figure 17: Option for user to select the spot test or to watch the animation again with visible contamination.).

In the case that the user selects the spot test, a panel pops up showing a still frame of the animation. The user must identify the problem area: in this case, this is the gloved hands. The user is able to try multiple times until they get this right (Figure 18). To reinforce the correct protocol, a layer of red at a 50% opacity is shown highlighting these areas (Figure 19: Spot test panel for Scenario 1, user selected correct area.). When they are ready, the user can then go back to the Scenario Selection menu and try out the next scenario.

### 4.5 Scenario 1: Phone Contamination with Visible Transmission

In the case that the user chooses to see the animation again with contamination showing, they are taken through to the same animation again, except this time Unity’s Particle Systems show where cross-contamination may occur as a result of the PPE violation (Figure 20). This is intended to facilitate the idea that when there is instant visual feedback, it is much easier to understand how your actions can be harmful. At the end of the animation, the spot test panel pops up and they can select the problem area.

### 4.6 Scenario 2: Mask Contamination

If the user selects Scenario 2 in the Scene Selection menu, they are shown the second animation using the same approach as the first scenario. This particular animation shows a paramedic tending to a patient and palpating the chest before touching the front of the mask (Figure 21).

### 4.7 Scenario 2: Mask Contamination with Visible Transmission

The user is able to see the animation again with contamination visible (Figure 22). Figure 23 shows the outcome of the spot test development for Scenario 2.

# 5 Discussion and Conclusion

## 5.1 Discussion

### 5.1.1 Evaluation of the Design Process

On the whole, the design process for the application went well. The final application hits the targets of wanting to create an educational tool about PPE protocol for paramedics, using cognitive load theory (van Merriënboer and Sweller, 2010) as a basis for instructional design. One particular aspect that was a success was the additional scenes of depicting cross-contamination to replace the initial plan of the transmission toggle. This approach has had similar success in raising awareness of the spread of bacteria in a veterinary setting (Macdonald et al., 2019). Although the toggle may have provided an additional interactive feature, the ability for the user to select a different scene, and therefore level of difficulty, depending on their level of experience and knowledge in the area is intended to facilitate the integrated to non-integrated strategy suggested by van Merriënboer and Sweller to combat expertise-reversal effect (van Merriënboer and Sweller, 2010). Whether donning and doffing is a relatively new procedure or one that the user is well versed in; the varying difficulty allows the user to use this educational tool with more autonomy.

### 5.1.2 Limitations

#### 5.1.2.1 Timings and Access to Resources

Significant factors presented issues, namely having to create the finished app within less than three months compounded by the situation regarding COVID-19. Due to the closure of GSA’s studio in response to social distancing measures, access to a suitable computer with fully functioning software was a challenge. As a result of the difficulty in accessing resources and the consequent time pressures, some of the intentions for the app were regrettably left out of the final application outcome. The first of these was the initial plan to have three different scenarios in the app. Given that animating in Maya was a completely new skill, it was unfortunately decided that having all three would compromise the quality of the animations so the third was forfeited, allowing more concentration to be focused on the first two. Given more time, further scenarios would have been developed, possibly to cover all aspects of PPE protocol, to allow the user to have a ‘fuller’ experience using the app; however, the final app does work well as a prototype in order to ascertain its effectiveness and scope as an educational tool.

#### 5.1.2.2 Animations

Another difficulty evident in the final application was the challenge of learning how to develop complicated animated sequences from scratch. As the paramedic character downloaded from Turbosquid (Table 2) came with a basic skeleton but was not completely rigged ie. did not have rig controls, it made the animation process much longer and more arduous. It also meant that realistic movement of the character was compromised – for example up-scaling an arm by accident when keying poses would not happen if the scale attributes had been locked. Having not learnt this before, dedicating more time to learn how to set up the control rig would have ensured the final animations were smoother and looked more realistic and may have even saved more time along the line. This came into play when feedback from supervisors the second animation suggested it needed to be re-done. The initial plan was to have the paramedic performing a simple procedure, using his stethoscope on the patient, however it quickly became apparent how difficult animating a dynamic stethoscope would be, so this was abandoned and replaced by a more ‘general’ animation of the paramedic tending to a patient. However, feedback from supervisors suggested this looked odd and distracting from the actual breach in PPE protocol. The time taken to alter an animation in the later stages of development was difficult, and ideally, given more time, this would have been refined and improved upon. Despite the problems with this stage, the model’s movements appear to be well executed and the action of violating PPE protocol comes across in them.

#### 5.1.2.3 Models

The use of downloaded models was not the initial intention; it would have been preferable to model from scratch all assets within the app to allow more creative freedom. This, again, was a result of the short window of time given to design the app and the need to prioritise certain aspects, such as the animation, over others. The paramedic model could have been improved, specifically with it being clearer that the character had gloves on. Due to the decision to make the app monochrome, this might not be particularly obvious – this then affects the user’s experience with this scenario. Additionally, it may have been effective to use a green shader on the PPE, ie. the gloves and mask in these scenarios, to further signify. This would have required more work on the paramedic’s model to separate the gloves from the main mesh.

### 5.1.3 Future Directions of Work

Unfortunately, despite putting out various calls for participants within the SAS to test the app (Appendix A), there were no sign-ups for testing, which caused difficulity in confirming the effectiveness of the app. This limitation was a result of the remote working, timing difficulties mentioned above and the understandable busy schedules of those working on fighting the COVID-19 pandemic. As testing was planned in advance, the documents needed, such as the Screening Questions and the Post-test Questionnaire (Appendix B-F) are all ready to go in the case that user evaluation is able to be carried out in the future. After using the app, the participants would be asked to fill out a questionnaire about their experience. The 30 questions use a 7-point Likert scale, ranging from strongly disagree to strongly agree, a system that many people will be familiar with. The statements are taken from recommendations for usability testing from the USE Questionnaire (Lund, 2001). Following these questions, the participant would also be asked what they least and most liked about the app and what they would change about it. This would give a chance for the participant to make comments on the experience outside the confinements of the scaled questions. In the event that this is used, it will be especially useful if the full version of the app was to be created.

The lack of ambulance guidance demonstrated in the literature may be due to the fact that guidance is generalised to all healthcare providers and therefore paramedic-specific PPE guidance is not necessary. However, as providers of emergency healthcare, it may be more common for paramedics to subconsciously slip up with PPE protocol in the more time-pressured environment; this can only be assumed as research surrounding paramedic behaviour in the context of PPE remains fairly undocumented. Again, this is why feedback after testing the app on paramedics would be particularly beneficial to determine the app’s eventual use. Depending on the outcome of testing investigation, it may appear to be more useful for the app to have a wider-reaching audience for not only those in the paramedic service, but for people that use PPE regularly. This technology has the potential to be widely distributed, specifically in order to tackle the impact the current pandemic in the UK has had on care homes, whereby staff may not have the skillset and materials to use PPE properly.

Additionally, the app could have potential in the midst of continually developing government guidelines around the public use of PPE, notably the mandatory use of face masks in some spaces to stem the spread of the virus. From observations in public and in the media, it is evident that the use of these masks is often incorrect, with the unfamiliarity leading to people frequently touching the front of the mask or only covering the mouth, whether this can be attributed to misinformation or sub-conscious slip-ups. Following successful testing of the app and positive feedback, there could be some scope for this app to extend to the public in the event that the compulsory use of PPE becomes long-term.

## 5.2 Conclusion

Since completing the research for this project on the 11th August 2020, the number of confirmed cases of COVID19 worldwide had reached 20.2 million (Worldometer, 2020). Since then, this number has increased five-fold. More than ever, the need for novel, emerging technologies combining visualisation and healthcare is paramount. In this chapter, a prototype of an educational, interactive tool for SAS clinicians has been developed as a proof of concept to investigate the potential for raising awareness of proper PPE protocol and the resulting contamination if not followed correctly. This has been supported by the review of previous studies on this subject and using the ideas from CLT to design the app as a piece of instructional media.

Although the effectiveness of the app is yet to be determined through testing, it is clear that What Not to Do with PPE was created from a well-defined concept and this was carried through to the finished app. The research would benefit hugely from further study; firstly, user evaluation, and secondly, the potential to broaden the content to a wider audience, whether this be the public or less specialised HCP. The results, therefore, presented in this dissertation uphold the use of an interactive application in the education of HCP, through the novel integration of 3D animation and interactive content.

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