A Scalable Interactive Mixed Reality Escape Room Simulation for Anatomy Learning

Xi Guo, Dai Rees, and Mark Richards

***Abstract*—Escape Room is an adventure game usually used for team building but can also be used to enhance group learning experiences, as teams need to solve problems to escape a locked room. Immersive technology such as Mixed Reality (MR) makes it possible to enhance users' experience of physical escape rooms with rich digital context. However, most MR designs require special equipment or applications to be installed and it is problematic to make the system scalable. While, most commercial products are used for entertainment purposes; in this paper, a scalable interactive MR escape room simulation for anatomy learning is introduced. This paper outlines the background, design concepts, implementation and test result. It demonstrates how to make good use of MR technology in a standard classroom setting, whilst combining the learning resources with an escape room game to provide a better learning experience in human anatomy.**

***Index Terms*—Mixed reality, augmented reality, escape room, web based, scalable, mobile application.**

I. Introduction

For all health professional education, soft skills such as teamwork and communication are as important as the core knowledge. However, traditional classroom-based teaching is limited when providing an environment with rich enough context for the students to practice and assess their performance in using both their knowledge and soft skills; including vital aspects of problem solving. Research finds that escape rooms are a good way of providing this simulated environment for group learning. [1]-[3].

However, it can be problematic to set up the physical requirements of a traditional escape room and resetting the scenario into the original state for every group [3]. In all educational environments, there are often time/space limits for each session. A computer simulated escape room can be an effective means to generate virtual scenarios. Applying recent immersive technology such as Virtual Reality (VR), Augmented Reality (AR) and Mixed Reality (MR) [4] to an escape room simulation, the scenario's presentation can be further extended from the physical world and create an innovative and engaging skill practice space for the users.

There are some previous works using VR, AR and MR to build a Virtual Learning Environment. [5]-[8] However, some of them rely on specialized devices or software which limits the location/timing due to the availability of the devices and/or software. Many use specific VR or AR technology and there are fewer using technology designed to bring MR simulation to an escape room. Moreover, many of the commercial escape room simulation products are specifically designed for entertainment and game play only. Currently, there is limited research or products simulating the use of problem solving, and specifically anatomical knowledge in an MR environment.

In this paper, a MR based online escape room system VERA (Virtual Escape Room - Anatomy) is introduced. The design of VERA combines a web-based 3D application as well as mobile AR application. It also combines a simple physical escape room setting together with Mixed Reality. The paper briefly defines VR, AR and MR technology which is the basis of the design. It is followed by an introduction to the VERA project background and related works. The more detailed system design will explain how to optimize its use. After that, system implementation and test result with a case study demonstrates how the system works. Finally, specific correlation of test results and a conclusion will be given for the application of this approach.

II. VR, AR and MR

According to Milgram, P. et al. [4], reality is the real-world environment that can be directly seen and felt. In contrast, Virtual Reality (VR) is a digital copy of reality stored in the computer. It blocks out the "real world" and makes the user feel that the virtual objects are real. Augmented Reality (AR) normally refers to digital elements superimposed on reality. It normally means visual elements but can also be extended to other senses such as sound, smell and touch [9]–[11]. Mixed Reality is in between Virtual Reality and Reality. It mixes the real world partially with virtual elements. Research shows that learners can learn quickly and happily by playing in virtual environments. [9], [10].

III. Background of Vera

Traditionally, escape room uses a story background to introduce a "task" to the participants (usually a group of 4¬6 members). The participants need to solve the puzzles as a team and unlock the room to escape. Computer escape room simulations are not new. There is some work already using VR and AR to build a Virtual escape room. An example would be Pendit, U.C. *et al*. [5] who developed a virtual reality escape room using mysterious elements to help users with a phobia of the dark and gloomy environments. Orr, T.J. *et al*. [6] introduced a virtual escape room for training mine workers. All interactions are based on an online computer simulation, but there is no significant detail on how scalable the software is and how hard it is to set up. Hermanns, M. *et*

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al. [7] introduced an escape room "toolbox" which included a web application triggered via a QR code. Although this work does not use any immersive technology, the use of smart phones to access web applications work well in combining with the physical quizzes. The AMELIO [8] is a project very similar to what this work proposes. It uses MR to create an immersive Escape Room environment. However, the system design is only aimed at team building training. Also, this project is limited by using specified devices and therefore is both difficult and expensive to scale at the moment. Some commercial products are also being developed. For example, "Escape the Room: AR" (produced by Canopy Interactive, LLC) and "Aria's Legacy" (produced by Afternoon Apps Inc.) which are mobile games using recent AR technology to put 3D based puzzles in your own room. However, they are not developed for educational purposes and the scenarios are static. Physical escape rooms have been used in Radiography courses at Birmingham City University (BCU) for team building and radiography knowledge testing. Although it gives a very positive result, the physical set up means it is limited on time/space when setting up for multiple groups, as well as in volume of content.

To overcome previous design limitations the VERA system was designed. The aim is to combine the learning resources with the immersive digital escape room game and create an interactive learning environment with rich multimedia context to enhance learning experience. Also, VERA is designed to be a scalable and easy-to-set-up system. That is, VERA is designed to be accessible anytime and anywhere without requiring special equipment other than a mobile device and/or a basic modern classroom setting – which is available in most Further and Higher Education Institutions. Additionally, using this system, user data can be collected and used for formative feedback in evaluating the learning process.

The VERA system simulates "travelling inside a body" using computer generated content and a smart phone AR application. The AR application simulates a virtual compass that projects X-ray image of the organs around current scenario. 4¬6 participants are invited for 30 minutes escape room sessions. They all play different roles in the room, e.g. "Captain" is the team leader, "Navigator" carries the mobile devices for navigation purposes. Although this design uses elements which can be considered as VR & AR separately, it is using MR as a whole project.

IV. System Design

The simulation is designed from three aspects. That is, simulation content design, user interaction design and software design.

A. Simulation Content Design

Simulation content is the key for the whole design process. The aim of the simulation content design process is to select and design the learning content to work well with suitable MR methods. Although MR in many research projects have proven to be effective and engaging, it is not a "one-size-fits-all" solution. To make sure the technology used is fit for purpose, a lot of discussion is required during the design. Questions to ask are: Why are existing methods are not good enough? Why is MR suitable for this content? What potential benefit it can bring to the learning process and how to achieve this?

After discussion, the human circulatory system was selected as it's usually just memorized and as such is time consuming and less practically relevant. Traditional learning materials with text and 2D images lack interaction, so it's hard to engage the learners. Using MR, it is possible to stir a participant's curiosity via the learning materials, presenting an impossible journey in real life.

In VERA simulation content design, both learning resources as well as MR presentation content are discussed.

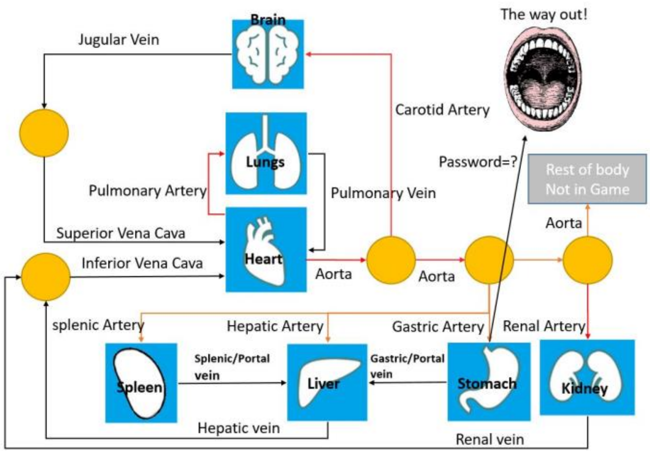

Fig. 1. Core learning content for VERA.

Fig. 1 shows the core learning "plan" for the VERA system – a simplified Circulatory System involving the major organs in human body. As shown in figure 1, there are 7 main organs and each organ includes some of the main blood vessels (yellow circles). Recognizing the current organ and finding the correct blood vessel to navigate, is key to travelling between different scenarios. The exit within the stomach requires a password to "escape"; via the mouth. Clues to the password are displayed by hotspots in the organs. A navigation clue Triggers an AR Radiography image revealing the relative position of organs to the current organ. By recognizing the image using radiographic knowledge, the participants can find the other organs to visit. A Time limit is added to the stomach to simulate the "acid attack". This trigger pushes the "spaceship" to the start point, the "heart".

MR content makes the scene interesting and immersive. For example, the 3D models with animation are designed to simulate the view of the "spaceship" travelling inside body, with the blood flow. Different background images and audio resources give clues as to the organ's identity. For example, breathing sounds are attached to an entering process, which gives a hint that the "spaceship" is traveling into the lungs. The background texture (Fig. 2) gives a hint this scenario might be the brain.

The simulation content design answered the core design questions for the VERA system. Making sure the design fits the learning aims. It also allows the participants have "free" space to develop their skills in problem solving that they can use in real life.

B. User Interaction Design

To make the most from simulation content, user interaction is important. The aim for user interaction design is to make sure the user gets the benefit of using mixed reality technology in engaging with the learning resources with minimum effort. That is, the design should focus on the goals of being "scalable", "easy to set up" and "minimal operational learning curve".

The first question is how to set up the interactive MR environment for an escape room simulation? Figure 2 demonstrates a standard set up for the system: Scenario screen with web applications simulating the "space ship" window scene, central desk area for physical interaction (with books, pen, paper, wireless mouse, keyboard and stopwatch) and a mobile device installed with the AR navigation app. This environment set up does not require special assets which mean it is possible to set up the system in any standard classroom or meeting room that provides a PC with a web browser and internet, speakers and a projector screen. Sometimes, to make the AR application works, it requires that there is enough ambient light in the classroom and a "marker" poster on the wall to make the AR work better. The design based on web/mobile application and standard classroom makes the VERA system scalable and easy to setup.

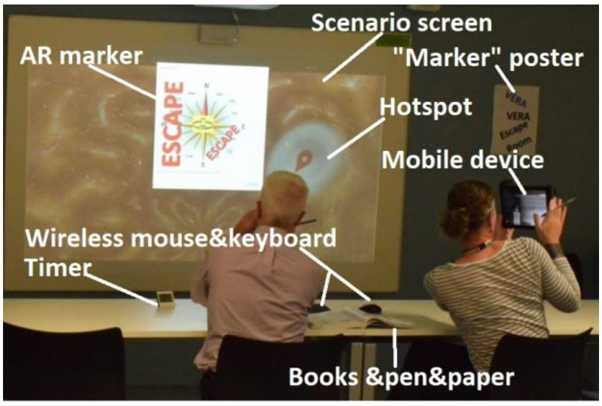

Fig. 2. Basic set up for VERA.

The second question is how to interact with the simulation content. Three interaction areas are provided for interacting with the system: the web application on the projector screen, the central desk and the AR mobile navigation application. Using mouse click and drag on the web application, the participants can trigger hotspots and look around the inside organ. By clicking the hotspot in the application; it allows the students to explore the clues hidden inside the scenario. A keyboard is used for password input. The central desk area simulates inside of the "spaceship" with a typical physical escape room setting. The participants can use books, pen and paper to record their findings on the "journey". Marker based AR is used in the mobile navigation application. That is, the AR application will be triggered once the mobile camera captures the "navigation clue" (AR marker image) from the projector screen. For example, as shown in Fig. 2, the "brain" scenario, the navigation hotspot is triggered. One of the participants scanned the compass image in popped out hotspot dialog using VERA the mobile application, some radiographic images appear on the screen. By moving the mobile device around the seating area, the participants can find images of other organs around the current "location". All three types of interaction are based on daily use of computers and mobile devices so minimizing the learning curve in using VERA.

Finally, performance assessment is important and valuable for both lecturers and students; interaction with the simulation can be the key for the performance assessment. Therefore, the VERA system is designed to collect all key user interaction information so that both the lecturers and the participants can get the most from using VERA.

C. Software Design

There are three challenges: Firstly, how to display an immersive 3D space simulation on the web? Secondly, how to reuse the scenario assets and generate scenarios at run time. Thirdly, how to collect the users' interaction information?

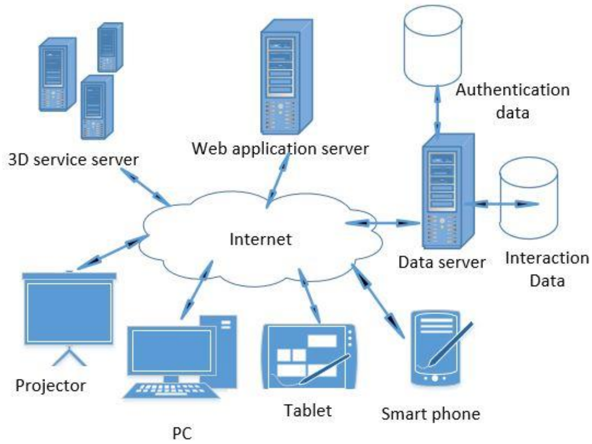

Fig. 3. System architecture design for VERA.

The system design is demonstrated in Fig. 3 and 4. Fig. 3 shows the overall system architecture. The system is deployed as three main services connected via the internet: 3D service server provides 3D models as well as a basic 3D web viewer. Web application server hosts all the VERA web applications for the simulation scenarios. Data servers host the database as well as its APIs (Application Program Interfaces) for both system authentication and user interaction record. The three services are linked via JavaScript APIs as well as RESTful services. In this way, the services can be replaced without influencing each other if there is a problem. Based on this architecture, it is possible to use professional web-based 3D storage services while put more focus on designing the system logic. Also, because the application system is based on web technology, it is possible to support different type of devices (For example, projectors in a classroom, PCs, tablets and smart phones) to access the system anytime and anywhere via a website.

Fig. 4 shows the detailed design of the web application. MVC (Model-View-Control) design pattern is used to generate an organ web scenario where three components need to work together:

- Data model for a scenario is carried by a description file to describe the references of all multimedia resources it uses;
- View elements include the actual storage of all multimedia resources (such as audios, images and a 3D model) and dialog models for the hotspots;
- The logic controller (including presentation controller and interaction controller) assembles the resources together to generate web scenarios and collects user interaction data.

There is an authentication framework on the top layer to provide user authentication for the web scenarios application. The mobile AR application interacts with the web application via marker images in the multimedia resources attached to the scenarios. Different AR navigation content will be triggered for different marker images displayed on the screen.

The presentation controller consists of a background controller and a hotspot controller, which is the core part to reuse the scenario assets and generate scenarios at run time. When a web scenario starts loading, the presentation controller finds its scenario description file and loads the resource list for generating the scenario. The background controller will generate the scenario by loading basic 3D model templates with corresponding background textures, hotspot components as well as the background audio if applicable. At the same time, the hotspot controller loads hotspot components in the corresponding positions and hides the ones that are not needed during the scenario. It also loads the relevant background texture for every hotspot (different hotspots can have different icon textures) and initiate pop-up dialogs using the dialog model written in the description file. There is also special dialog content triggered by a timer rather than a hotspot click. The timer is also described in the scenario description file. Currently the stomach scenario uses this type of dialog to simulate an "acid attack" alert. As a result, the presentation controller then generates the 3D web scenarios as well as all the hotspots with embed trigger dialogs at run time.

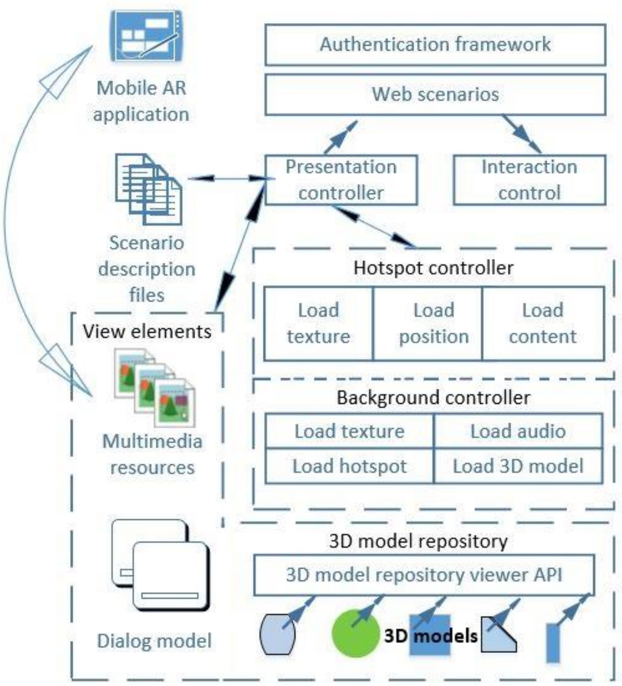

Fig. 4. Design for VERA web application.

The interaction controller is responsible for collecting user interaction information. The information includes clicks on the hotspot, screen clicks, drag & drop as well as entering a scenario and the end of the escape room session. When any interaction event happens, the information will be sent in JSON messages to the database service with a timestamp. As mentioned in Fig. 3, there are two types of database in the system. One type of database is the traditional relation database used for authentication data. A NoSQL database stores the interaction data. The reason for this is, that although the interaction information can be structured using the key event feature "where, when, what, who" pattern, it is hard to find a "one-size-fit-all" format. For example, if a clue hotspot is clicked the message will contain the clue object name as well as the organ name. If the interaction is only recording the entering of an organ only the organ name is recorded. NoSQL databases provide a flexible way for structuring and retrieving the interaction data.

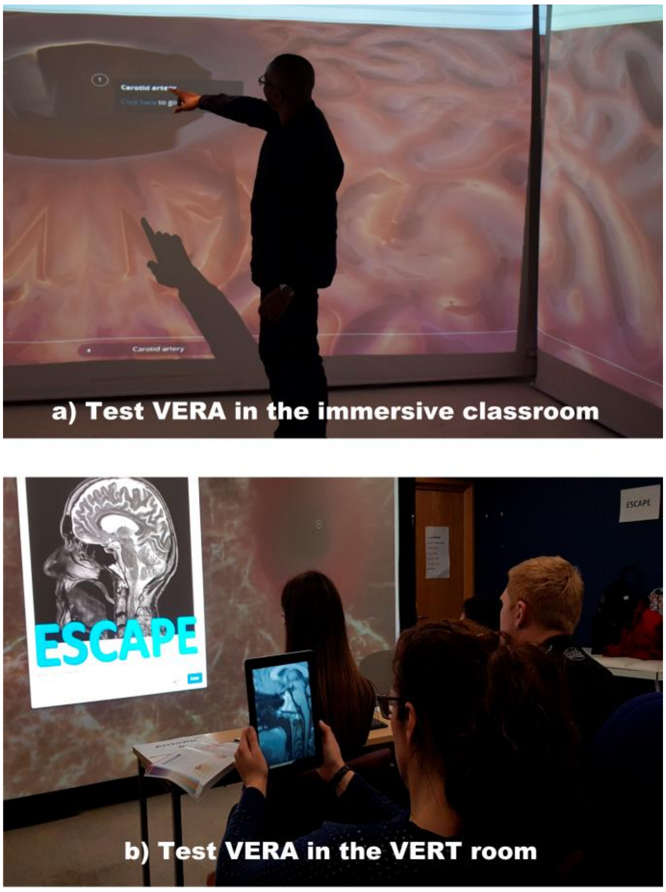

Fig. 5. VERA test result in classrooms with support.

V. Implementation and Test

The software is implemented using PhP, HTML and JavaScript for the web application. Bootstrap is used for user interface displays to make sure it can adapt to different screen sizes. To implement the 3D interaction a cloud 3D services Sketchfab is used to host the animated 3D models. Sketchfab is not only a 3D repository but also provides APIs to change 3D model features. Using a JavaScript library called "Sketchfab Viewer API utility", it is possible to build the interaction control logic for the 3D objects. The AR application component is implemented using Vuforia and Unity. MySQL database stores the authentication data and MongoDB stores the interaction data.

When launching the system, Google Chrome is used as the web browser. Other facilities for the escape room include: a stopwatch, an anatomy reference book, pen, paper, wireless mouse & keyboard and a tablet or smart phone with the VERA navigation application installed. During the study, both Tablets and Smart phones are provided for the participants to choose for themselves.

Before recruiting students to VERA, it was tested in different sized classrooms including an immersive classroom (shown in Fig. 5. a), VERT (Virtual Environment for Radiotherapy Training) room (shown in Fig. 5. b) and some standard classrooms with different screen sizes (shown in Fig. 2). The results showed that the system can adapt to different screens very well. As in Fig. 5. a, the immersive classroom's 3 wall projectors created an ideal display of the 3D based scenarios. The VERT room also gave better MR display compatibility. The standard classroom provided less immersive visual effect, but still worked as designed. The mobile devices can launch the AR navigation in various sized classrooms. Due to the limitations of Vuforia engine, careful lighting and sometimes extra markers are needed to make the image stable. Also, the AR software performs better on the newer generation mobile devices.

10 students were recruited for the pilot runs and 14 students for system test after upgrading the system used in the pilot study. This paper describes the design of the upgraded system. A case study for using the system is described as below:

The simulation starts with the scenario introduction animation from the lecturer avatar in the 'spaceship'. When the team chooses to enter the game, the screen loads the heart scenario with the animation of travelling inside blood vessels. Heartbeat sounds can be heard during this animation. There are five hotspots in the heart scenario with number icons, one hotspot with an information icon and one hotspot with a navigation icon. When clicking the numbered hotspots, a dialog displays the name of the blood vessel. If the team chooses to enter a hotspot with an entrance to another organ, the corresponding organ scenario will be loaded on the screen. An unavailable entrance will alert the team the blood flow direction is wrong. The information hotspot will display a dialog with clues to the 'escape' password. When over a navigation hotspot a symbol of a compass is displayed, it cues the 'navigator' to turn on the navigation app on the mobile device and scan the 'compass' AR marker. Radiographic images will then appear on the mobile device. By moving the mobile device around in 3600, the user can find other nearby organs such as stomach, spleen and kidney using their radiography knowledge. If the team stays too long in the stomach, an acid attack alert will display and redirect the team to the heart scenario. If the team works out the correct password (input in the stomach) they will be directed to an animation of escaping via the mouth with a cheering sound.

The test results show the system design fits the purpose of anatomical learning. According to the after-test interview, most of the students gave positive feedback about using the system. The feedback phrases they used to describe VERA experience are "good way to learn", "fun" and "interactive". Some commented on "confusion" and "sickness" when the moving animation was running, or they were moving the mobile device around.

VI. Conclusion and Future Work

As a scalable interactive MR escape room simulation for anatomy learning, VERA combines MR anatomy simulation with a physical escape room and is accessible via a web application and a mobile application, anytime and anywhere. The design focuses on "easy to set up" and "a minimal operational learning curve" and so increases its usability for both lecturers and students. The design makes good use of MR technology, allows dynamic generation of web scenarios, enhances the interaction with AR mobile applications and the interaction data is automatically collected to support performance analysis.

There are some limitations which will require future work. Firstly, more test runs are needed to evaluate if this method works better than a physical escape room. Secondly, the limitations of the Vuforia plugin can make the AR application unstable. More work is needed to fix this problem. Thirdly, the interactions using MR technology is still limited in this project. Finally, the application of the findings is limited by the small sample size. In the future, more MR interaction methods can be applied to enhance the immersive user experience and one of our current foci is to find an algorithm to help assess the participants' performance.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Xi Guo lead the research, simulation software design & implementation. Dai Rees lead the initial concept, design & script for educational content and ran the student research sessions. Xi and Dai wrote the paper. Mark Richards produced 3D models and animations for the project.

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