A Case Study into the Use of Virtual Reality and Gamification in Ophthalmology Training

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Abstract. In collaboration with doctors and medical students a novel ophthalmology training solution based upon virtual reality (VR) and gamification was developed. Fifteen fourth year medical students at Birmingham City Hospital (UK) helped evaluate it. Evaluations were based upon the Technology Acceptance Model and related to how well users learnt to use the app, their satisfaction with it; if it helped them learn ophthalmology and their view on the teaching approach used within it. Responses were rated on a five point Likert scale (completely agreed to completely disagree). Results represent those that agreed or completely agreed with the questions. Students agreed they could easily learn how to use the app (n:14) and it was clear how to use (n:15). The feedback systems supported both this (n:11) as well as learning how to perform eye examinations (n:13). Users felt the app improved their understanding of the processes involved in ophthalmology (n: 14); their ability to recognize main landmarks of the eye (n:14) and abnormalities (n:15). They felt the app would give them confidence to perform eye examinations on patients in future (n:12) and it would increase other students' confidence too (n: 15). Users found the app enjoyable to use (n:15); would use it in future (n:13) and would like to learn other clinical skills in this way (n:15). A rigorous User-Centred approach has been used to successfully develop a novel ophthalmology training tool. The approach used will help inform others interested in developing VR educational tools.

Keywords: Virtual reality · Gamification · Ophthalmology · Medical training · Technology Acceptance Model

1 Introduction

During their training medical students will be required to become proficient in a range of clinical skills which may be challenging to learn. One skill that medical students find difficult to perform are eye examinations [1], meaning that an important diagnostic procedure can become underutilized [2]. Previous studies have shown that simulations using medical photographs have helped students understand ophthalmology procedures before moving onto working with patients [3, 4] by incorporating gamification [5]

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students have also reported that it can improve their engagement with their learning of challenging and difficult clinical topics too [6, 7].

Successful adoption of new practices and technologies can be very dependent upon the active involvement of users. User-Centred design aims to ensure that risks are mitigated against rather than relying on retrospective fixes to poorly designed systems which are more likely to be under used or misused [8]. Subsequent evaluation provides confidence that the systems are effective and Fit-For-Purpose which is becoming an issue with medical apps as concerns have been raised about their proliferation without any suitable testing and validation [9, 10]. Finding appropriate evaluations of technologies in clinical settings can be challenging as technology is quick to change. Regular access to trainee doctors to help with testing can be difficult too. All of this can mean that if evaluations are not conducted in a timely manner the system could soon become Out-Of-Date. However there still needs to be a high level of confidence that the system produced is useable, accurate and efficacious. The Technology Acceptance Model [11] offers one potential solution to the challenges associated with testing in clinical settings in a way that has been previously validated in other settings. This paper describes how a novel ophthalmology training app was developed and evaluated in collaboration with doctors and medical students. It was built using commercial smart phone technology and affordable virtual reality (VR) head mounted displays (HMD). By incorporating actual clinical photographs and utilizing gamification an app was produced which was intended to be both clinically accurate as well as being both fun to use and educational.

2 Methods

2.1 Collaborative Design

In order to identify how HMD VR could be used in clinical training preliminary discussions were conducted between two clinical teachers (DC and LT) together with a medical student and two technologists (ASW and JO). After demonstrating how VR works it was decided that an ophthalmology training app could be developed which could take advantage of its functionality. Real-Life use of an ophthalmoscope is influenced by numerous factors for example patients find it hard to keep their eye still or the student does not have a big enough field of view to identify important land marks in the eye. Therefore the app would be designed to help students understand overcome these type of problems by incorporating different types of movement, orientations and visual field restriction. The addition of gamification and education strategies would be used to make this difficult to master technique fun to learn and structure the way the students' learn the systematic step wise processes used when examining the back of the eye.

2.2 Development Hardware and Software

The app was developed using Unity 3D 4.6.6, C# and the Microsoft.NET framework version 4.5.1+. Other software included the Java Runtime Environment version 8+, Java SE Development Kit version 8+, Microsoft Visual Studio 2013 premium, Android stand alone SDK and the Google Cardboard SDK for Unity. A custom text to speech synthesis program was coded by one of the authors (JO) using C# and the Microsoft Speech Synthesis API.

2.3 Deployment Environment

Google Cardboard 1 and Ritech II Virtual Reality HMDs were used in the development. The app was tested on HTC one 801N and Samsung Galaxy S5 phones. Google Cardboard 1 or RITECH II require the phones to have both gyroscope and magnetometer (digital compass), this is so the HMD's external button can interact with the app. Google Cardboard II and Ritech Riem3 Plus are also supported. These substitute the magnetic button with a lever on the HMD that touches the mobile phone's screen. Figure 1 shows the Ritech Riem3 Plus HDM and mobile phone as well as the stereoscopic view of the retina displayed by the app on the phone.

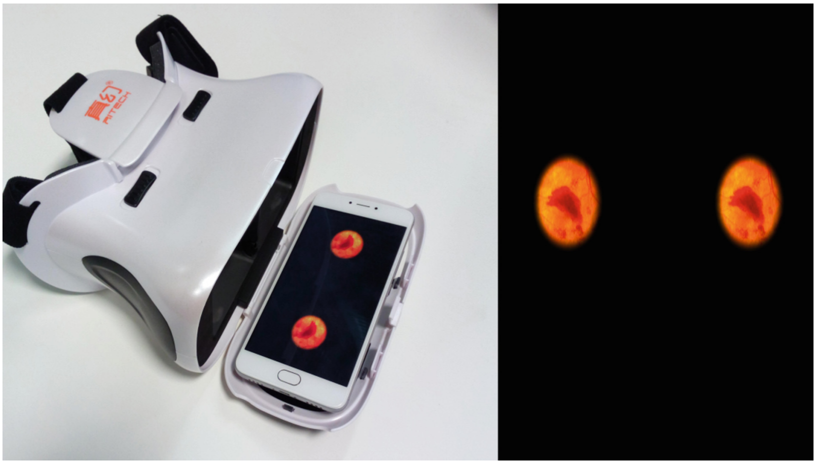

Fig. 1. Ritech Riem3 and smart phone [left]. Stereoscopic view of retinal images with haemorrhage [right]. The fixed aperture size in the app restricts what the user can see mimicking the actual view through an ophthalmoscope

2.4 The Ophthalmology App

The app has five levels including a tutorial, red reflex, retinal navigation, pathologies and quiz. It uses a range of authentic clinical photographs of both normal and abnormal eyes. Audio, visual and text provide instruction on how to use it; how to perform eye examinations and also gives descriptions on the different types of pathology that can be found in the retina.

The Tutorial Level. This requires the user to look around and search for objects in the 3D world learning how to navigate the environment. The user has to press the HMD button in order to interact with objects which are the main form of interaction between the program and the device. If the user fails to press the button with sufficient force audio cues prompt the user to press the button harder until it activates. As the button is the primary way of interacting with the program an alternative mechanism was required for the user to access the menus. Given the limited functionality of the Google Cardboard SDK the best option available was to have the user tilt the phone 90° in order to activate app's menus.

The Red Reflex Level. This requires the user to orient the virtual ophthalmoscope's light to make the retina visible. In order to successfully complete this level the user has to position the virtual light until the red reflex appears in the avatar's eyes. By using the HMD trigger they can also zoom in and out of each eye in order to get a more detailed view of the retina.

The Retinal Navigation Level. The user receives audio visual information explaining how to navigate four quadrants of the retina by following its main blood vessels. Users are assisted by audio cues informing them when they have reached specific way-points. The user is required to correctly identify the optic disc by using the HMD's button to click on the relevant area. Subsequently they can click on the retina to simulate how the patient would look into the ophthalmoscopes light in order to see the macula in greater detail. Finally the user is given a narrated overview of the steps they have just completed.

The Pathologies Level. Audio visual narrations are given on common pathologies of the eye. These include cotton wool spots (Fig. 2), haemorrhages and papilloedema. The user is given an overview of the abnormality before being shown annotated images describing how they occur. The user then has to identify that pathology in another image without accompanying explanations. At the end of this a narration explains each of the abnormalities again. The user can then test their knowledge in the quiz level.

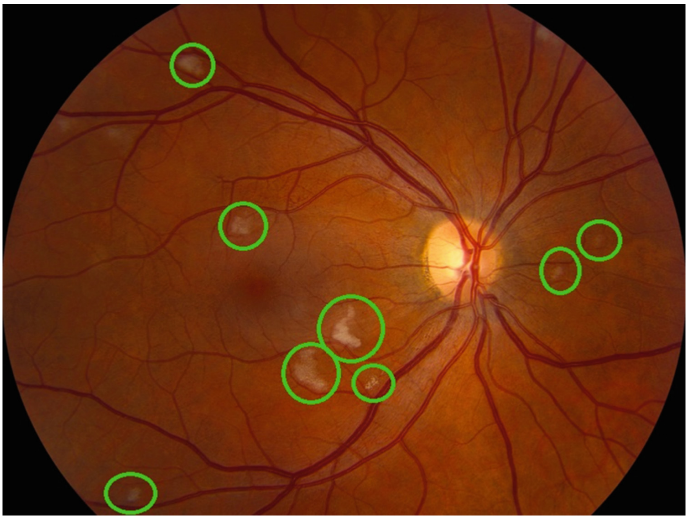

Fig. 2. Retinal image with cotton wool spots highlighted for the user

The Quiz Level. The user is shown eight random images of eyes which could have no abnormalities, cotton wool spots, swollen optic disc or haemorrhage. The user has to examine the eye using the processes they have previously learnt and then identify whether it is normal or exhibits one of the pathologies. If the user incorrectly identifies the image they are provided with feedback which explains the pathology they have just been looking at and what characteristics they should have identified. Figure 3 describes the process followed by the user.

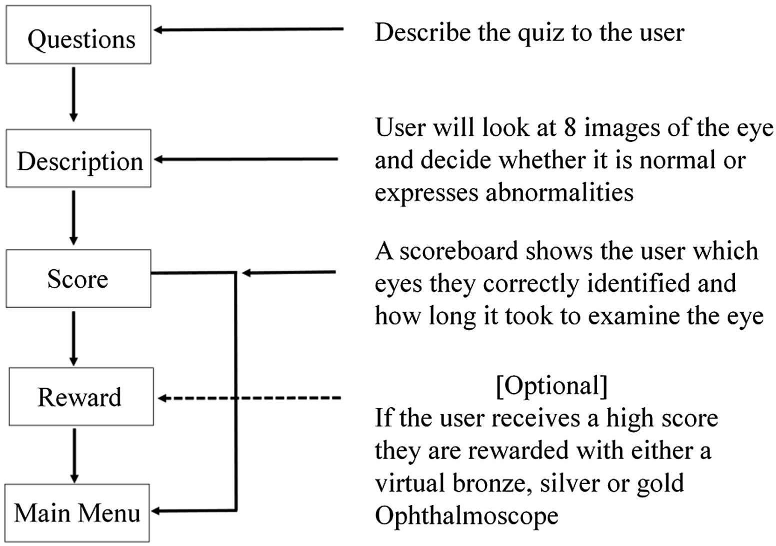

Fig. 3. Flow diagram illustrating the processes involved in the quiz level

Gamification. A scoring system within the app awards points for successfully completing each of the activities within the level. A reward icon is also awarded signifying they have successfully completed the level. At the end of the quiz the user sees a scoreboard within the app showing them the number of correct identifications they have made together with the average time they took to identify them. There is an optional award of another badge signifying their overall level of achievement in this quiz (bronze, silver or gold). Table 1 summarizes the levels, a description of the procedures the user needs to follow and the reward system that was implemented.

Internal Usability Testing. This was conducted with eight members of staff in the Faculty of Computing, Engineering and the Built Environment, Birmingham City University (UK). Each was asked to test prototypes of the app and provide feedback on it. They had no previous experiencing of using VR and did not have a medical background. Items evaluated included rating its ease of use, determining whether the tutorial was explanatory to them, the quality of feedback given in the app, and how long it took them to complete the program. They were also asked to identify any problems with the app's functionality.

Table 1. Scoring and rewards systems for each level

Level	Description	Gamification
Tutorial	Teaches the user how to use the app and interact with virtual objects	No points or rewards for this level
Red reflex	Simulates the process of correctly orienting the ophthalmoscope relative to the eye resulting in the retina becoming clear to the user	25 points awarded for correctly achieving the red reflex in each eye. Total 50 points for completing level. Reward icon for successfully completing the level
Retinal navigation	Background information is provided on the procedures. The user learns to correctly navigate the retina and identify important landmarks such as the optic disc	25 points awarded for identifying the optic disc. 25 points awarded for navigating each of the four quadrants of the eye. Total 125 points for completing level. Reward icon for successfully completing the level
Pathologies	Narrated description and annotated images describing how three types of abnormality occur within the retina. The user has to identify that abnormality in a new image	25 points awarded for correctly identifying cotton wool spots, haemorrhage or papilloedema. Total 75 points for completing level. Reward icon assigned for completing the level
Quiz level	The user is presented with a random image of the retina. User has to identify the pathology by selecting from a list of options which include no abnormalities, cotton wool spots, swollen optic disc or haemorrhage	There are 8 questions in total. Each successfully answered question is scored by dividing 50 by the average time taken to complete each question in the quiz (in seconds) Optional quiz rewards: Gold ophthalmoscope 350 + total points scored in the quiz Silver ophthalmoscope 300 + total points scored in the quiz Bronze ophthalmoscope 250 + total points scored in the quiz

External Usability Testing and Evaluation. This was conducted with the assistance of fifteen, fourth year medical students. They were surveyed for their opinions on the app as part of one of their routine clinical teaching sessions at Birmingham City Hospital (UK). All of them voluntarily agreed to help provide feedback on the app as a teaching tool. Questions were based on 1. How well they felt that they learnt how to use the app, 2. Their satisfaction with it, 3. How well they felt the app helped them learn ophthalmology and 4. Their views on the teaching approach used. Users' responses were rated on a five point Likert scale which ranged from completely agree to completely disagree. Table 2 shows the themes and questions.

Table 2. Survey of medical students' views on the app

Theme	Statement
Learning to use the app	Learning to use the app would be easy for me I can learn to use the app quickly and easily I would find it easy to control the app so it will do what I want it to Working with the app is clear and understandable to me I found that the feedback system supported my understanding of how to use it Overall I find it easy to use the app I would find it easy to understand how to use the app in future
Satisfaction with the app	I find using the app enjoyable to use I would use the app in future as the technology is appealing to me I am completely satisfied with the app
Learning ophthalmology	The app improves my understanding of ophthalmology processes The app improves my ability to identify the main landmarks in the eye The app improves my ability to recognize abnormalities within the eye The app will give me the confidence to better able to perform this task on a person in future The app makes me curious to learn more about ophthalmology and the eye
Teaching approach	I found the teaching approach used within the app informative I found that the feedback system within the app supported my learning about ophthalmology I would use the app in future as the teaching approach is appealing to me I believe that app will increase students' confidence when performing these tasks on a patient in future I would like to be taught other medical skills in this way in future

3 Results

3.1 Internal Usability Testing

Of the eight users (Birmingham City University) who agree to help evaluate the app 7 of them felt that it was easy to use giving it an average rating of 4.4/5. All felt the tutorial level was clear and helped them understand how to use the app. All testers successfully worked through all of the levels with a mean time to completion of 7.43 ± 3.1 min.

3.2 External Evaluation and Feedback

The app was rated positively (combining agree and totally agree responses) by all of the medical students (n:15). Figure 4 shows the responses to their views on how well they managed to learn how to use the app and their satisfaction with it. The respondents to the survey agreed that learning to use the app would be easy for them (n:14), they could learn to use it quickly and easily (n:15) and control how to use it (n:13). They felt that working with the app was clear and understandable (n:15), with the built in feedback system supporting their understanding of how to use it (n:11). Overall they found the app easy to use it (n:15) and they would know how to use it again it future (n:15).

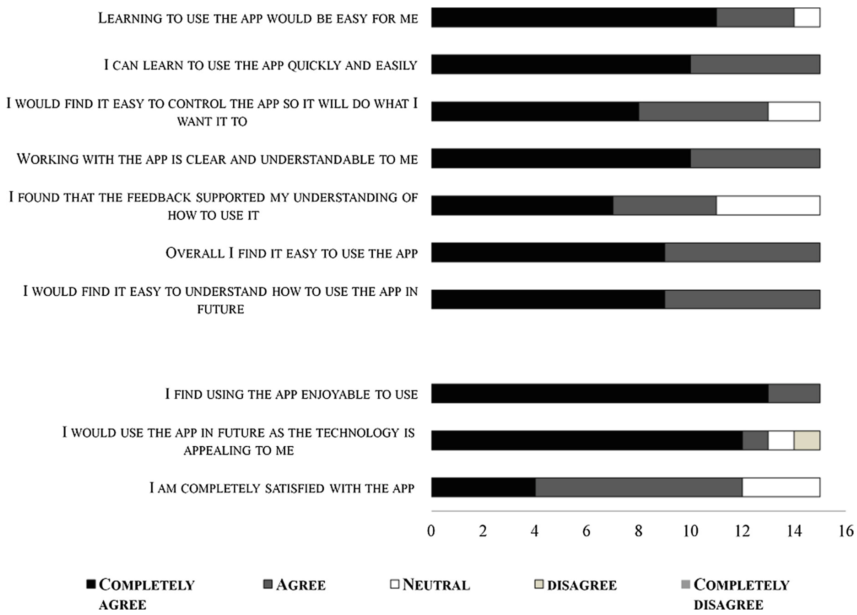

Fig. 4. Rating the app for learning how to use it and user satisfaction

All users found the app enjoyable to use (n:15) and they would like to use it in future as the technology is appealing to them (n:13). The majority (n:12) were completely satisfied with the app. Figure 5 shows the medical students' views on how well they thought the app helped them learn ophthalmology and their views on the teaching approach used within the app.

The users felt that the app improved their understanding of the processes involved in ophthalmology (n:14), their ability to identify the main landmarks in the eye (n:14) and recognize abnormalities (n:15). They felt that the app would give them confidence when performing an eye examination on a person in future (n:12). The app made them more curious to learn more about both ophthalmology and the eye (n:13).

With respect to the teaching approach used within the app they found it informative (n:13) with the app's feedback system supported their learning how to perform eye examinations (n:13). They would use the app in future as the teaching approach was appealing to them (n:15). They felt that using the app would increase students' confidence when performing these tasks on a patient in future (n:15) and that the teaching approach would be useful in order to learn other medical skills in this way (n:15).

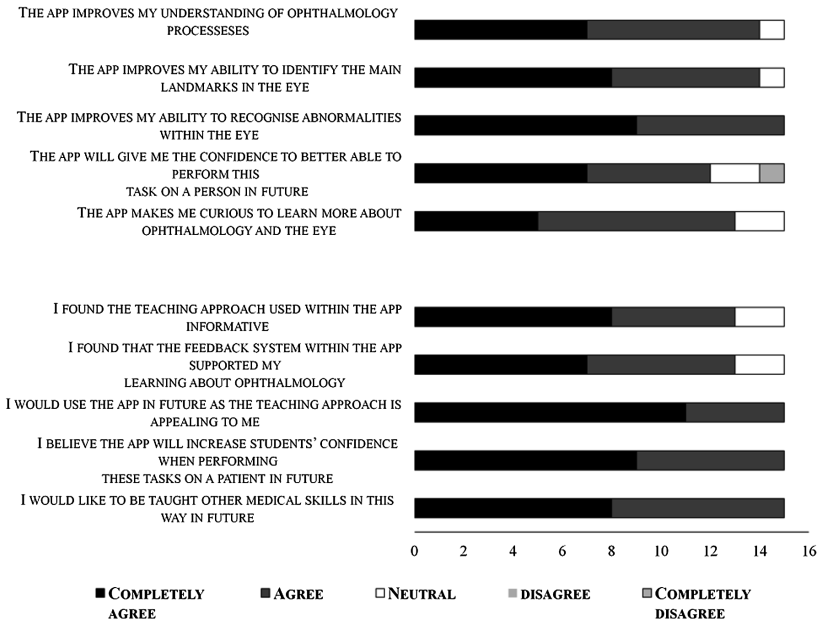

Fig. 5. Rating the app for learning how to perform ophthalmology procedures and teaching approach

4 Discussion

In this study the authors have shown that by collaborating with doctors and medical students VR apps can be developed that offer a way of engaging students in learning about complex clinical topics. The medical students who helped us had little prior experience of VR, therefore we set out to create an app that was fun, easy and intuitive to use. Key to supporting how to self-learn how to use the app was the introduction of a tutorial level which was fun to engage with, so that less technical users felt comfortable in learning how to use it and did not become frustrated by trying to learn too many complex actions too quickly. By carefully staging the following levels more complex clinical processes were taught building on them each time. At any stage the user could repeat the level as many times as they liked before moving onto progressively more difficult tasks

Regular usability tests were conducted both with naïve users who were not medically trained and had no prior experience of using VR as well as with medical students themselves. The results showed that all users could successfully learn how to use the app with minimal formal training. The evaluations also proved to be useful as they quickly highlighted that the external button mounted on the HMD (Google cardboard 1 and Ritech II) could be problematical with users not always using sufficient force to activate it. This prompted the introduction of audio cues which encouraged the user to apply more force to activate the button. Audio feedback was also incorporated as it was identified that 2D text in a 3D environment could be difficult for all users to read. The audio cues and narratives also minimized disruption to the flow of activities when conducting investigations of the eye, helping and guiding the user whilst they concentrated on performing the required tasks. The initial usability tests also highlighted that the time needed to complete the activities within the app was also important as the battery life of the mobile phone is limited restricting what can be done for example the total number of levels available.

Although this app was successful in the trials reported in this study the knowledge base associated with ophthalmology is very dependent on understanding other clinical elements too. Therefore the app is not meant to fully replicate the process of using an ophthalmoscope rather it is used to help demonstrate how to perform the step wise systematic processes used when examining the back of the eye and how to correctly identify any important pathology. Gamification (scores and rewards) was incorporated into the clinical skills training element of the program in order to make the learning experience fun, adding competitive challenges to encourage students to work towards correctly performing the required processes and to try and motivate them to continue to engage with the app. Gamification in combination with the audio narratives were also used to provide feedback so that the user was aware that they had correctly followed the required steps.

Evaluation was based upon the Technology Acceptance Model [11] rather than a controlled trial format which is standard practice in clinical research. It was felt that in these early studies that this would be more efficient, would require fewer medical students and would still give important feedback on both the students' perceptions of the app and most importantly whether they felt it improved their confidence in being able to perform eye examinations. Using a previously validated assessment tool meant that there was confidence that the app was Fit-For-Purpose resulting in it being introduced as a teaching tool into the hospital relatively quickly. This evaluation procedure proved to be both helpful and informative in the development of the app. More in-depth studies we wish to make in future include comparing students' use of an ophthalmoscope after standard teaching and standard teaching plus use of the app as well as identifying whether that app had any impact on any summative assessments where students have been required to demonstrate their understanding of how to use an ophthalmoscope to identify clinical pathologies.

5 Conclusion

In this paper the authors describe the successful development of a novel VR based ophthalmology training app that has been developed to assist students in their understanding of ophthalmoscopy and eye pathologies. The creation of the app was intended to give students more confidence when subsequently practicing these skills on real patients which is a key outcome of their clinical training. The evaluation with the medical students showed that they found the app easy to use, they were confident that they would be able to understand how to use it again in future; the teaching approach used in the app was informative and supported their learning about the procedures used in ophthalmology. The authors found that overall satisfaction with the app was very high and that the students felt more confident in being able to conduct this procedure on patients in future.

6 Ethics

The Faculty of Computing, Engineering and the Built Environment at Birmingham City University (UK) ethics committee were informed about the study. This type of student survey is standard practice in Birmingham City Hospital (UK) when medical students' views on new approaches to learning and teaching are being sought. It would not be expected to be placed before its ethics committee however the medical school were aware of the project.

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Conflict of Interest. The authors declare that they have no conflict of interest.

Virtual Reality App. A demonstration version of the VR app can be requested from the corresponding author.

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