Usability and UX evaluation of an online interactive virtual learning environment: a case study of Wales' virtual hospital

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Abstract
Clinical placements are an essential component of the education provision for students of medicine and other health professions. However, opportunities to achieve learning outcomes cannot be consistent across students due to the very nature of their exposure to different patients in different timeframes and settings. In addition, the unpredictability of attendance of patients and the impact of the COVID-19 pandemic has resulted in few opportunities to experience more than one point in a patient journey. An innovative online virtual environment named Wales' Virtual Hospital (WVH) was developed using agile software development and User-Centred Design approach. This research paper presents the comprehensive usability and user experience (UX) studies that were conducted to evaluate all aspects of WVH by end-users and experts. The main contribution of this research is in the case study of evaluating a newly developed innovative online virtual environment, where behavioural and subjective feedback were collected to test the usability and the effectiveness of the learning experience. For this paper not all the outcomes of the evaluation process are reported, instead a key outcome of each iterative cycle is given as an example. The evaluation approach developed and used in this research could be adopted by other researchers to evaluate similar systems.

Keywords
VR, Educational Challenges, Usability, User Evaluation, Expert Evaluation.

Introduction
Medical learning requires a multimodal approach, with the need to offer students up-to-date evidence-based knowledge and the explanation of processes and key procedures (Philippe et al., 2020). Alongside scientific theory and the use of multimedia or online-resources, a core part of supporting medical students involves practical elements, such as placements in clinical settings. Clinical placements are considered an essential component of the education provision for students of medicine and other health professions. It enables the vital and unique experience of applying textbook knowledge to 'real' patients and the demands of an often-evolving clinical situation.

However, in clinical placements opportunities to achieve learning outcomes cannot be consistent across students due to the very nature of their exposure to different patients in different timeframes and settings. Hence, not all students will have the chance to experience a variety of specialisms, departments, and see the vast number of presenting complaints and patients (Life Sciences Hub Wales, 2022). As a result, students often see only one point of the patient's journey. Furthermore, the COVID-19 pandemic has brought a more critical challenge to experiential learning with face-to-face interaction becoming limited (Pears et al., 2020; Chan et al., 2021). Simulation can be used to augment clinical placements (Schiza et al., 2020, Macnamara et al., 2021). This learning technique provides strong engagement and offers students many technical skills. It offers the chance to learn from situational awareness, making judgements, and implementing practical processes (e.g., fitting a catheter) without affecting the safety of a real patient, and the opportunity to receive feedback and a debrief on their performance (Chao et al., 2022).

Immersive technologies such as Virtual Reality (VR) have received a lot of positive attention in the fields of medical education, with evidence to show that it creates realistic and interactive simulations; supporting the transmission of knowledge; instilling emotional engagement; role expectation and learning by doing (Dubovi, 2022). This should complement other forms of teaching and training and not be used as a substitution (Bruno, et al., 2020).

However, creating medical scenarios, such as 3D-modelled wards featuring virtual patients and colleagues using computer-generated environments, can be quite expensive to produce, especially when creating multiple scenarios for different types of clinical situations. Using 360° video, which is sometimes referred to as VR because it can be viewed in a VR Headset, gives the students an omnidirectional field of view simply by moving their head to look around, providing a passive sense of immersion (Snelson & Hsu, 2020). The limitation is that they cannot interact in the same way as the computer-generated environments where they can walk around, interact with objects, and feel more present in the experience (Huang, et al., 2020; Witmer & Singer, 1998).

To address some of the limitations of clinical placements and to develop an inexpensive VR content creation platform that would allow clinicians to generate bespoke content, an innovative online virtual environment named Wales' Virtual Hospital (WVH) was developed. The design of the virtual environment allows clinicians or academics to create three types of interactive learning experience framed around a patient presentation in three formats: 360° still environment, 360° video environment, and fully immersive 360° VR environment. The goal is to build a library of medical case studies from a range of specialisms and to deliver more experiential learning of healthcare, with opportunities for interactivity in the form of answering questions as the content progresses. Clinicians or academics can use an online toolkit named the "Creator Mode" (CM) to create the different types of interactive learning experiences. This can be done by recording 360° video content which is currently very inexpensive, available to a consumer market, and easy to set-up and capture (Harrington et al., 2018). Students would be able to access the "Viewer Mode" (VM) portal to view the content and interact with it on their mobile, computer, or VR Head Mounted Display (HMD). As part of the WVH system, students would also be able to answer key questions as the scenario progressed, allowing them to make judgement calls at different stages through a graphical interface, which would appear within the 360° environment. Clinicians or academics can view students' engagement data using "Data Mode" (DM) toolkit (e.g., number of correct or wrong answers).

The development of WVH was carried out by integrating Agile software development approach and User-Centred Design approach (UCD). This resulted in more frequent usability evaluation iterations and a systematic way to examine and confirm end-user needs (Jurca, et al., 2014). Research shows that iterative evaluation and refinement cycles are essential to develop an educational intervention (Sandars & Lafferty, 2010). As the WVH system relies on collaboration between the academics, recording and uploading 360° videos and creating the interactive content and then the students engaging with it, it is important to make the system user-friendly, with intuitive functionality, for both types of users (Fisher and Wright, 2010). This would encourage its adoption into the course pedagogy and ensure learning opportunities are effective and optimised. In this paper, we present the comprehensive usability and UX studies that were conducted to evaluate all aspects of WVH system by end-users and experts. The aim was to ensure that the system design adhere to design principles and meet users' needs, across the WVH system modes, and making the delivery of the interactive virtual learning content more streamlined and engaging for the users.

Evaluation Method

Figure 1 illustrates the experimental approach that was adopted to critically evaluate the usability of the different types of modes and interactive learning experiences created using the WVH system, and to measure the effectiveness of these learning experiences. An iterative development cycle and testing with both experts and end-users were conducted while working closely with the WVH development team. The expert evaluation technique is typically conducted by professionals who have a high level of expertise in a particular field or subject matter (Ghaoui, 2005), in the case of this project Human-Computer Interaction and Design specialists. Experts used their knowledge and skills to assess the usability of the system and user learning experience. Whereas end-user evaluation technique involves collecting feedback from actual users of a product or service (Ghaoui, 2005). This approach allowed for a more practical and realistic assessment of WVH system, as it is based on the experiences and needs of the users (i.e., students, lecturers, and clinicians).

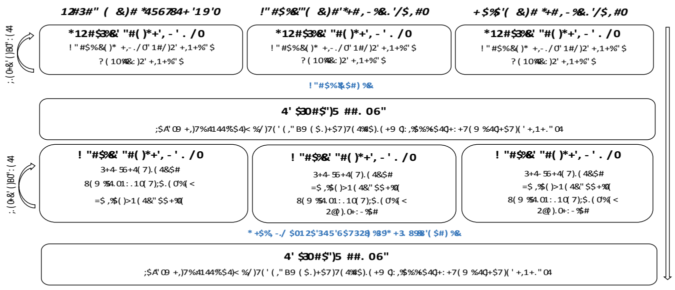

Figure 1. Evaluation Approach

Expert-based Evaluation:

Three expert evaluators evaluated the system's three different modes with the different level of interactions. This evaluation process was iterative starting with early conceptual prototypes and finishing with a high-fidelity prototype. Two expert evaluation techniques were followed, this included:

- » Cognitive walkthrough (CW): This rigorous expert analysis technique was used to check through the system design and logic of steps in user interaction (Lewis & Wharton, 1997). The focus of this technique was on evaluating the learnability of the system from the perspective of new or infrequent users. The evaluation was structured around three design principles: visibility, affordance, and feedback (Donald, 2013). During the evaluation process the expert evaluators went through the user tasks provided by the development team and discussed the four key questions cited by Wharton and his colleagues (1994).
- » Heuristic Evaluation (HE): This usability engineering technique allowed the expert evaluators to go through the system design looking for usability problems, guided by Jakob Nielsen's standard usability heuristics (Nielsen and Molich, 1990; Nielsen 1994) and visual-design principles (Gordon, 2020). At the end of the session evaluators rated the identified usability problems using the severity rating scales for impact by Nielsen (1994). The severity ratings created a priority list for the development team to work on to improve the system. Nielsen's standard usability heuristics were chosen as they are relevant when evaluating the different modes of interaction (Joyce, 2021) and for educational systems (Mohamed & Jaafar, 2010).

The expert-based evaluation techniques were regarded as a first pass of evaluation to identify as many usability problems as possible. This was followed by user-based evaluation to focus the evaluation further.

User-based Evaluation:

A total of 12 medical students evaluated the VM using the different levels of interactions. Individual testing sessions were conducted at ATiC's laboratory on the high-fidelity prototype of the system with five students (VR mode) and remotely with seven students (other modes). The CM and DM of the system were evaluated by five professionals (clinicians and academics). Research shows that 85% of usability problems can be identified with five participants (Asarbakhsh & Sandras, 2013).

Task scenario-based sessions using thinking aloud protocol: Participants were invited to complete a series of tasks related to the key activities they need to complete to use the system. Participants were provided with scenarios to give them an explanation and context (Dumas & Redish, 1999). As participants move through the system to complete the tasks, they were asked to verbalise their thoughts, feelings, and *opinions*.

Behavioural observation: To avoid the observer effect (Blalock & Blalock, 1982; Bloombaum 1983), the user-based evaluation sessions were video recorded using Noldus Viso system and screen capturing software for tracing and recording participants' actions and navigation. Allowing the researchers to analyse the participants' system interaction retrospectively. Observations were made on the key metrics of *Effectiveness* (were participants able to complete the tasks with a high degree of accuracy), *Efficiency* (how fast can participants complete a task) and *Errors* (how many errors do participants make and how easy it is to recover from those errors). To allow for a more visual presentation of the user interaction (Andrade, 2018), Tobii eye tracking was used to capture users' unconscious behavior, preference, and to understand their decision-making.

Post-session interviews: Semi-structured interview sessions aimed to collect more detailed feedback from participants on the following aspects:

- Likelihood of use: thoughts on the likelihood of themselves and other students using the system.
- Content and learning experience: the quality of the educational content available and what could be added; how effective and efficient this type of experience on learning; thoughts on the feedback they get from interacting with the system; and finally explore if the multiple-choice question is the best way to test students' knowledge and learning.
- Utility: does the system offer the functions that end-users need.
- Overall experience and usability: aesthetics; typography; learnability (ease of learning); ease of use; memorability (ease of remembering), and overall satisfaction.

Post- session online questionnaire: The online questionnaire consisted of three sections:

- System Usability Scale (SUS): a simple and reliable standard 10 item questionnaire with 5-point Likert scale used to collect participants' subjective feedback. The SUS was chosen as it is a well-researched and widely used to evaluate similar systems (Brooke, 2013; Orfanou, Tselios, & Katsanos, 2015; Renaut, et al., 2006).
- Look and feel of the design, consisted of four statements with 5-point Likert scale, which investigated participants' thoughts on different aspects of the design.
- Satisfaction: a statement with 5-point Likert scale about how satisfied participants are with the overall experience using the system.

Implementation & Results:

For this paper, an example of each iterative evaluation study will be discussed to highlight a key finding of that evaluation study and to illustrate how the evaluation method presented in this paper was implemented. Hence, not all the detailed feedback from the expert and user evaluation which has been shared with the development team is discussed here.

The first round of the iterative process was carried out with early WVH prototype of the VM using CW technique, the objective of this study was to evaluate two scenarios using the different level of interaction. The evaluators walked through the system thoroughly inspecting the two scenarios several times and completing a series of tasks. The outcome of each task was presented in the format illustrated in Table 1. A representative task of this study was to locate and enter the bay number 06. Once the participant was in the bay, they were required to check some important information about the patient (e.g., patient history, ECG; Figure 2).

Table 1. The outcome of a cognitive walkthrough

CW questions	CW Answers
Will users try to achieve the right effect?	**Yes.** Users will be able to attempt to enter the bay and find the key patient information.
Will users notice that the correct action is available?	**No**. Not everyone will look around naturally. Users should be provided with information on how to navigate the 360 environment and what actions will take place all around them or what interactive elements will appear.
Will users associate the correct action with the result they're trying to achieve?	**No.** Important interface components, or actionable items should not be placed too far from each other.
After the action is performed, will users see that progress is made toward the goal?	**Yes.** When the users click on the white dot to enter the bay the user is taken to inside the bay. Every time the user click on the actionable items inside the bay the user is presented with the related information.

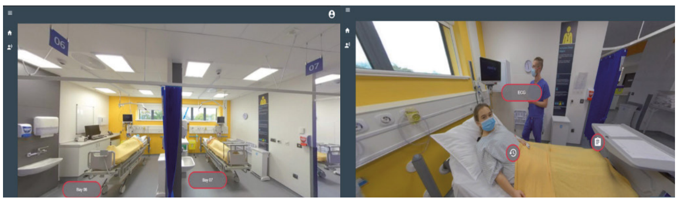

Figure 2. Screen shots of the WVH viewer mode in a Shift Scenario

All the problems encountered in this study were categorised under four themes: (1) navigation; (2) interactivity; (3) feedback given to users; (4) visual communication. The problems were shared with the development team with a list of recommendations to improve on the design. The improved prototype was then tested with medical students using the user-based evaluation method discussed previously.

In this study participants evaluated a scenario using Oculus Quest VR headset. All participants said they could see themselves and other students using the system. Overall, participants found the experience engaging and fun. The immersive environment as participants noted gave them the experience of 'being there', which supports memory and practice-based learning. All participants commented on how it may benefit the way they learn best – by being in the role and in the hospital (such as on a clinical work-placement). They could see potential as to how this platform could support practice-based learning – or used as a library for extending their knowledge. They also said it may better develop their experiences for areas where they may not have had the opportunity first-hand. Two participants thought the video quality was not 'crisp', and that they felt they were 'floating' within the VR environment. However, this did not present a large problem towards overall UX. Unfortunately, none of the participants were able to complete all the tasks as the system kept crashing before reaching the end of the scenario. However, if we considered the number of tasks they completed before the system crashes, then all participants were able to complete all the tasks with a high degree of accuracy. On average efficiency level was 14 minutes (SD=0.7), and no errors were made (getting a question wrong was not counted as an error).

In the follow-up interviews, three participants said that they did not realise that answers were behind them, with one participant wondering whether they could be brought forward, but then became undecided because they recognised that having to search the environment for answers suits the immersive format. Participants suggested that having a fixed number of answer options would encourage them to look around for them. Participants commented on the quality of the production of the scenarios (e.g., quality of acting skills) which could be improved based on the content created by clinicians. Generally, participants found the structure of the scenarios very useful to test their knowledge and learn from any mistakes. Participants found the multiple-choice format useful for both learning and testing.

In this version of the prototype, SUS mean score was 78 (Grade B, Good) with a standard deviation (SD) of 6.2. Participants thought the system offered the functions that they need, and they were happy with its look and feel. Overall, all participants were very satisfied with the system.

Table 2. The outcome of heuristic evaluation

Heuristic	Ratings	Problems encountered
Visibility of system status	2	It is not clear which of the text fields are optional and which are compulsory. The appropriate feedback is presented, however, the display time of the error message is too short to read.
Match between system and the real world	1	'Preview Image' does not indicate upload image. Consider clearer labelling.
User control and freedom	4	Unable to upload a video making it hard to complete the task of creating a marked scenario.
Consistency and standards	1	Inconsistency in labelling, when selecting an image from the "Images Library" the dialog box labelled 'Select Media' and then you are presented with 'Select Images'.
Error prevention	1	You are allowed to select two images as scenario cover even though you only need one. Users should be constrained from selecting more than one image.

The iterative process of evaluating each design cycle continued with another round of expert evaluation of the re-designed VM, and the newly developed CM and DM. For each mode a series of tasks were tested. For the purpose of this paper, one example of a representative task from evaluating the CM will be used to illustrate the process (See Table 2). The task was to create a marked scenario, adding a stopping point at 30 seconds with one correct and two wrong answers. The evaluator should then move and place these answers in a location in the 360° environment. The outcome of the CM evaluation uncovered some violation of the design principles. As shown in Table 2, one of the encountered problems prevented the evaluators from completing the task. In contrast, both the VM and DM insights were mostly positive, where most of Nielsen's Heuristics were adhered to. After fixing the problems identified by the experts another round of user-based evaluation was conducted. Where medical students evaluated the VM, and professionals evaluated the CM and DM.

The updated version of the VM scored 84 (SD=13) (Grade A, Excellent) on SUS an improvement from the last round of evaluation. The system, as participants noted, was user-friendly, easy to access with clear graphic design, navigation, and interactivity. However, the audio quality during part of the scenario was reported as "poor" by some participants. Answers placed spatially around the scene were still causing some confusion to several participants. Participants were generally satisfied with the learning experience.

CM and DM were evaluated by clinicians and academics. In the CM, participants were tasked to create new learning content using the platform. The task involved building a 360° virtual scenario: inputting information, uploading videos and images, and then creating questions and answers and placing them within the 360° virtual space. All users had no prior experience and were still able to complete the task effectively, with some commenting that they would have no problems reprising the task now they had completed it once, adding that an initial demonstration video would have better prepared them. Two key challenges users encountered were (1) understanding how to move (or look) around the 360° content within the preview windows; (2) the choice of symbols and their placement in the interface.

Users began by setting up their scenario content by inputting basic information and uploading media. Following typing a title and description, many users were hesitant regarding two buttons, "Show to Users" and "3D Video", before progressing. This can be seen in the eye tracking data in Figure 3, where they fixated on these elements overall. It was not clear to us-

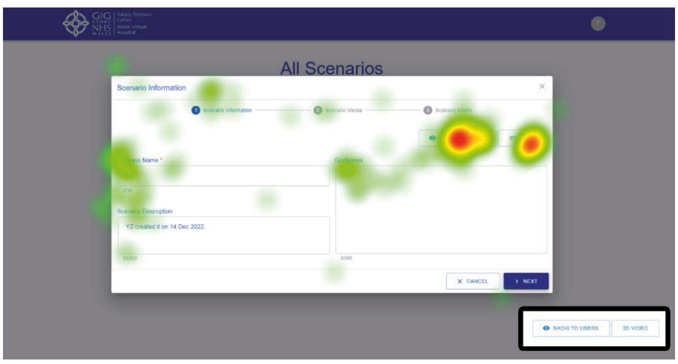

Figure 3. A heat-map of scenario information page

ers that these buttons were in fact switches, and by clicking them it would toggle on/off different options for the scenario.

Following uploading 360° video content, users were presented with a window titled "Camera Centre" displaying a preview image of the video with a symbol of a target in the centre. Upon hovering, the cursor would change from an arrow to a hand icon, which indicated to users they could interact or move this element. All users tried to click and drag the target symbol first to move the 360° video, which had no effect, rather than clicking the background or the image to move the perspective. This can be seen in eye tracking data in Figure 4.

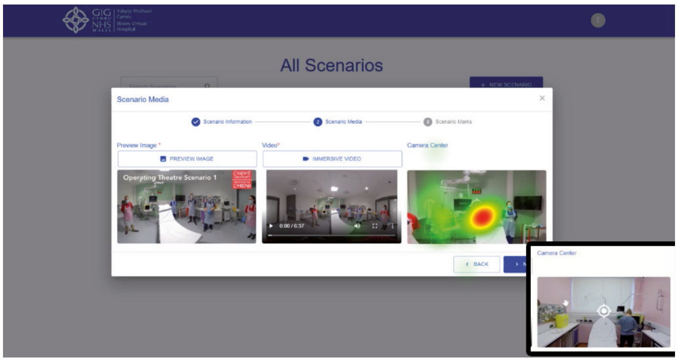

Figure 4. A heat-map of scenario media page

In the final screen, users can input questions and answers into their 360° scenario at any moment during the playback of video. There were specific challenges when placing answer boxes within the 360° environment. Each answer box had three symbols, a target, a pencil, and a tick or cross to denote if it was created as a right or wrong answer. Users assumed the pencil would allow them to 'edit' and move the answer box, instead this sent their cursor to the text entry box on the right. Upon clicking the target, it changed to a green computer disk icon, this would save the location of the answer in the 360° environment. However, it wasn't clear that users had to now move the background video by clicking and dragging, and instead users tried to drag the answer box. Once this process was finally worked out, users tried to click the green tick (representing 'correct answer') instead of the disk symbol. The eye-tracking heat-map reveals a definite focus on the green tick symbol (Figure 5).

CM and DM scored 69 (SD=10) and 71 (SD=13) on SUS respectively (Grade B, Good). Overall participants were somewhat satisfied with both modes, with all participants suggesting that having a demo instruction video for first time users would have increased their satisfaction rate.

At the end of each design and evaluation cycle, all project partners and stakeholders were invited for an informal evaluation testing session. The outcome of these sessions feedback to the next design cycle with all the data collected via expert and user evaluation.

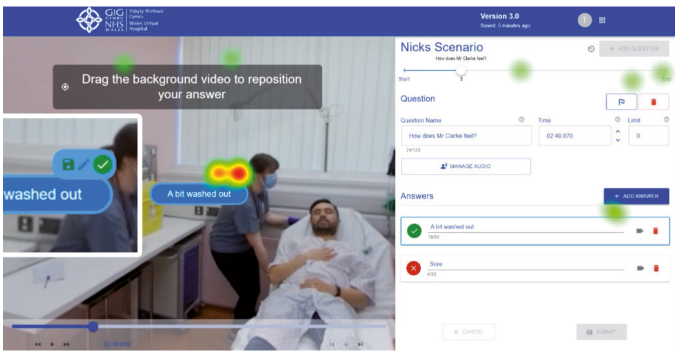

Figure 5. A heat-map of the final page where users can add questions and answers

Discussion and Recommendations

Conducting the evaluation in this thorough and rigorous manner allowed for a more comprehensive and well-rounded understanding of the designed system and led to better decision-making and improvements to the system.

The paper offers insights on how to evaluate an interactive educational system using the different interactions levels. Designers and project teams should take in consideration the following:

- It is crucial to start validating design ideas at the early design stage and continue evaluating the system throughout the whole development process.
- The findings from the expert-based and user-based evaluation complemented each other as they provided different perspectives. The expert-based evaluation can be regarded as a first pass of evaluation to identify as many usability, design, and technical problems as possible. While the user-based evaluation highlighted user-experience issues and areas where the system did not meet the needs of the users.
- By combining the two approaches and collecting both subjective and behavioral data, it is possible to validate and confirm findings from both approaches. This helps ensure that the findings of the evaluation process are accurate and reliable.

The case study of evaluating the newly developed innovative online virtual environment contributes to research in this field by demonstrating how this evaluation methodology, where iterative collection of behavioural and subjective feedback is undertaken, can be used to test the usability and effectiveness of similar systems. However, there are some limitations of this research that need to be addressed, especially regarding evaluating the effectiveness of the learning experience. This research has only collected subjective feedback from students. Further research is planned to investigate the effect of VR simulation teaching prior to in-person simulation training. The research will involve 300 medical students using the Randomised Control Trial (RCT) method. In addition, there was no comparison between different levels of interaction to understand which students preferred or found more engaging. Lastly, future evaluations could be further strengthened by increasing the sample size.

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