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PAPER

Analyzing and Designing the Utility of Virtual Reality for Nursing Fundamentals Lab

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ABSTRACT

The COVID-19 pandemic prompted many universities worldwide to adopt distance learning, creating a significant gap in hands-on skills training, particularly in health and nursing education. To address this challenge, this study presents the analysis and design of a virtual reality (VR) application, NursingXR, developed to support training of students in performing procedures related to the fundamentals of nursing labs in undergraduate programs. The study proposes a hybrid approach that utilizes the multimedia development life cycle (MDLC) alongside hierarchical task analysis (HTA) and unified modeling language (UML) diagrams to provide developers with essential information for implementing NursingXR. A prototype was developed as a validation step, based on the analysis, design and data/material collection phases. Additionally, interviews with nursing instructors were conducted to explore how the platform can complement traditional learning and training modules. The findings indicate that the proposed approach is effective for developing VR applications in the healthcare domain.

KEYWORDS

virtual reality (VR), nursing training, analysis and design phases, multimedia development life cycle (MDLC), hierarchical task analysis (HTA), unified modeling language (UML), design requirements

1 INTRODUCTION

With many higher educational institutions around the world adopting the use of distance learning during the COVID-19 pandemic, different learning management systems, such as MOODLE, CANVAS, etc., were provided for teachers and students to ensure the seamlessness of the learning process. Such platforms enable teachers to deliver lectures, share materials, and conduct assessments synchronously or asynchronously. However, for nursing students who require hands-on training and practical skills, distance learning poses a number of obstacles and challenges to acquiring the required knowledge and skills.

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The difficulty in obtaining hands-on skills for a wide range of simulation labs and other practical courses taught in a clinical context is considered a drawback of adopting distance learning for nursing undergraduate programs. According to [1], due to COVID-19 pandemic, many nursing students were not able to attend hospitals for practical training. Another obstacle is related to the lack of interaction and feedback from their teachers compared to those received in traditional classroom settings. This can increase the load on the students, which leads to frustration and increases dropout rates among nursing students who are following online or distance learning programs [2]. Distance learning also poses challenges for skill acquisition related to emergency procedures and safety training [3]. Further challenges are discussed in [4], [5]. Such challenges lead to the need for innovative solutions to complement the teaching and learning process. Innovative solutions provide more realistic and interactive learning experiences in online or distance learning.

Nowadays, the proliferation of new technology presents a chance to provide different effective solutions in the educational domain that can enhance the teaching of procedures in nursing labs. The importance of utilizing technology in education and clinical practices was raised early [6]. Among the possible technologies, virtual reality (VR) has been considered by scholars to investigate the possibility of alleviating the previously mentioned obstacles in teaching practical courses and labs not only in healthcare and nursing faculties [1] but also in engineering faculties [7], [8], and the computer science domain [9]. According to the report [10], experts predict that the global market for VR in education will grow from 16.42 USD billion in 2024 to 61.55 USD billion in 2028. The report highlighted that some major VR companies are developing innovative VR solutions for inclusive training in the healthcare sector. This interest from academia and industry domains in utilizing VR is mainly because of the ability to provide interesting, immersive, and interactive 3D environments [11].

As part of an international collaboration project between Arab American University in Palestine and Shenandoah University in the USA, this project aims to explore the integration of NursingXR into nursing courses, focusing on the technical aspects of implementing a VR system, examining how nursing educators can effectively incorporate VR-based training modules into their courses, and understanding how students perceive and benefit from this innovative approach.

Recognizing that thorough analysis and design are pivotal for the successful implementation and adoption of VR systems, this study proposes robust initial phases—analysis and design—for developing NursingXR. The proposed solution involves creating scenario-based models to simulate various procedures in a fundamental nursing lab, identifying design and functional requirements, and utilizing both hierarchical task analysis (HTA) and UML modeling approaches. What sets this study apart work is its emphasis on providing technical insights and suggesting a hybrid development approach based on the early stages of the multimedia development life cycle (MDLC) [12]. To validate the proposed hybrid approach, a rapid prototype of the NursingXR was implemented and interviews with nursing teachers were conducted. The technical implementation and end-user evaluation of the final version of NursingXR are out of this paper's scope and will be thoroughly presented and discussed in another research article.

2 RELATED WORK

Virtual reality technology has gained significant popularity over the years and motivated a large body of research in different topics related to the medical domain. It was noted that most of the previous research did not provide details concerning technical challenges or methodology for developing VR applications for training and education in healthcare. One of the common development methodologies adopted for VR applications is the MDLC with different interpretations for its phases [12]. MDLC was also adopted to develop augmented reality applications such as the work presented in [13] and to develop an adventure educational game [14]. Results in previous studies showed the effectiveness of the developed solutions using the MDLC approach. However, there is a limited number of research studies related to VR development using MDLC. Research work presented in [15], [16] employed MDLC to develop a virtual interactive campus tour using 360-degree technology. The provided VR solution offers an immersive experience for students so that they are able to virtually explore university campuses and discover the available facilities and services on the campuses.

Most of the works published in the academic literature focus on presenting the different functionalities of the proposed VR solutions in the health domain rather than showing the early stages of the development approach. Nevertheless, there are some exceptions related to other domains. For instance, researchers in [17] confirm the effect of a task-centered approach (using HTA) on the usability aspects of VR user interaction to improve worksite safety. Another study [18] used HTA to develop a VR simulation for shoulder arthroscopy for rotator cuff ailments to quantify the surgery performance. Also, researchers in [19] used HTA to develop a VR rehabilitation application to improve the abilities of those who acquired brain injury. Researchers in [20] showed how HTA was used to describe tasks and subtasks for a VR simulation related to the critical importance of cricothyroidotomy (CCT). The developed VR application was mainly based on recorded 360-degree videos. Another study [21] showed the usefulness of HTA in a surgical procedure during space flight using 360-degree technology. Also, it was noted that HTA was utilized to show the breakdown of tasks of the endoscopic sleeve gastroplasty (ESG) procedure [22]. Accordingly, this validates the use of HTA in defining health procedures.

Unified modeling language (UML) diagrams were also used in developing VR applications and video games. There is limited research referencing UML for VR development. For instance, [23] presents the use of use case diagrams, activity diagrams, and sequence diagrams to develop a flood disaster management VR application. Researchers in [24], [25] mentioned that UML was used to design and implement a VR-based game for improving students' computational thinking competencies and skills. The utilized UML diagrams were use case, activity diagram, and sequence diagram. The work showed the effectiveness of using UML to develop a smart learning environment using VR to help students learn programming concepts. The developed prototype was implemented using the Unity3D engine. Other research work [25], [26], [27], and [28] developed a VR programming environment for UML visualization, which allows programmers to solve complex programming tasks in a VR environment. Other work [29], [30] explores the potential of integrating systems modeling language (SysML) with VR environments to enhance the understanding of complex systems engineering. Based on [31], UML is used to design the user interface, interaction inside VR headsets, and gesture recognition for a VR game. The focus of the previously mentioned articles mainly depends on UML diagrams without showing more details related to task analysis and procedure protocols. Limited attempts were conducted to investigate the use of UML and HTA such as [32], which shows the validity of using UML in designing a web interface.

To the best of our knowledge, this is the first research work that presents a hybrid development approach that combines MDLC, HTA, and UML to analyze, design, and develop a VR solution for the fundamentals of nursing lab.

3 RESEARCH METHOD

After identifying the research problem, which is that nursing students find difficulties in acquiring skills related to nursing labs during distance learning, the research work proposes a solution that utilizes VR technology in the teaching and learning process in such practical courses by developing NursingXR. Similar to previous studies [12], [13], to be able to develop NursingXR, the MDLC was adopted. MDLC consists of analysis and conceptualization, designing, collecting data and materials, assembling, testing, and distributing materials.

Based on reviewing a number of studies [22], [33], [34], [35], MDLC has some limitations for developing VR applications. First, it has a limited emphasis on user-centered design, and it focuses on functionalities rather than user experience. Therefore, there is a need to involve users in early testing to have a realistic, natural, and intuitive user experience in VR applications. Second, the MDLC approach has a lacking flexibility for rapid prototyping. Rapid prototyping allows for developing testable VR experiences to gather user feedback and iterate on the design phase. To overcome the previously mentioned limitation, our proposed approach adopts MDLC alongside HTA and UML, as both can ensure dignifying tasks align with how teachers and students use the nursing procedures, and they can provide more insight for visualized interactions between users and VR applications.

The focus of this paper is on utilizing HTA and UML in initial stages of MDLC (concepts, design, and collecting materials) to develop NursingXR in the context of the collaboration project, which has different steps and subtasks in each step (see Figure 1). Starting with the first step (analysis and conceptualization), since NursingXR is a non-linear and interactive product, the related sub tasks are proposed as follows: 1) specifying targeted users and lab context and characteristics; 2) exploration of the hardware and software specifications; 3) providing task analysis; and 4) identification of design and functional requirements.

In the design step, the modeling of NursingXR using UML diagrams (use case, activity, components, and deployment diagrams) is considered to be a general-purpose modeling language in NursingXR, which provides a standard way of communication and visualization of VR applications.

The collecting materials and data step is composed of four tasks. 1) identifying 3D virtual environment characteristics and components; 2) listing media assets such as 3D objects, audio, video, text, images, etc. and creating identified media assets. 3) scripting animation attached to different 3D objects; and 4) storing all produced resources in a repository.

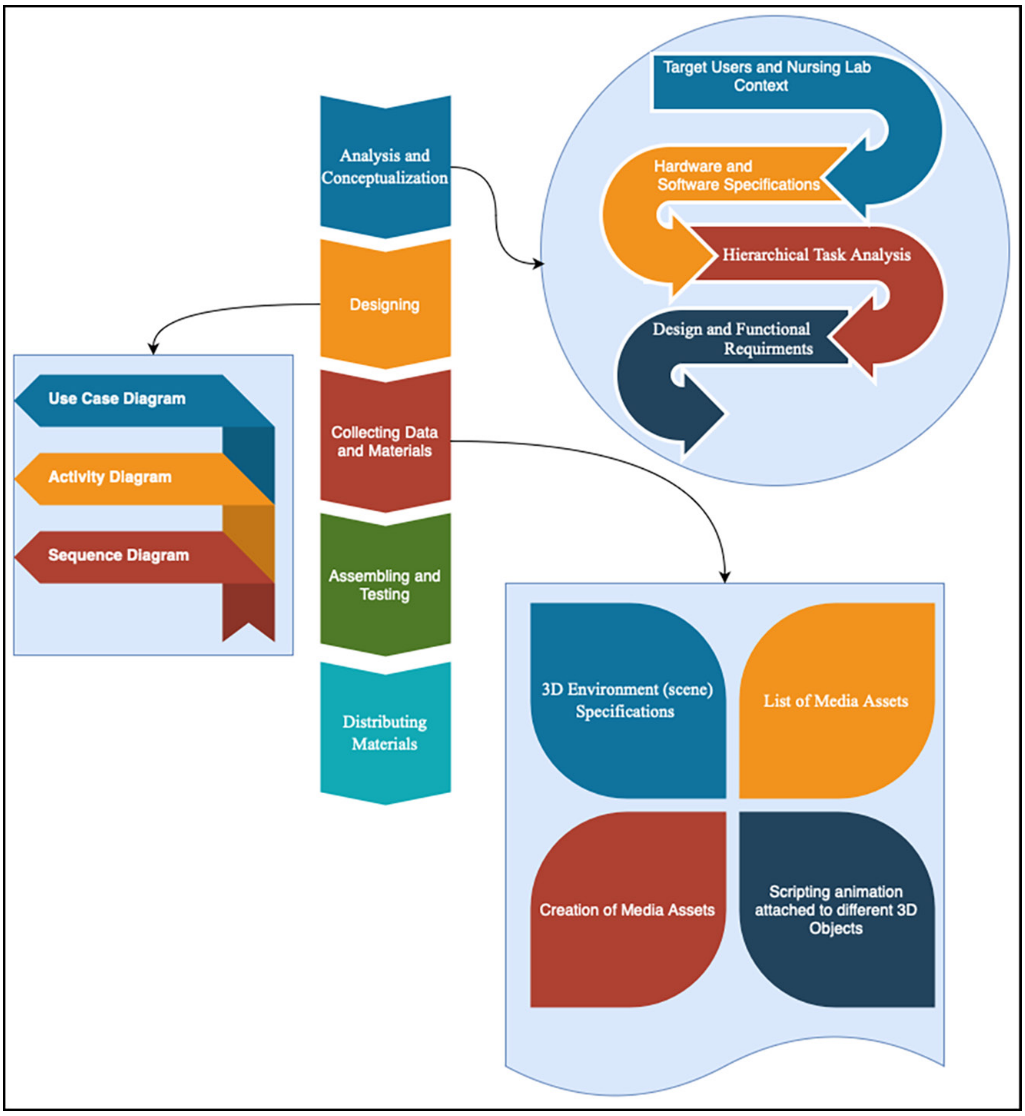


Fig. 1. Hybrid and iterative MDLC for VR development

3.1 Concept and analysis phase

Considering the traditional approaches [36], [37], concept and analysis phase includes a set of guidelines and iterative steps to be conducted to help in analyzing any software application. Starting with identification and characterization of target users and environmental context, clear identification of tasks to be performed by the user using the application, and listing a set of system design requirements and functional requirements. The subsections provide an analysis of NursingXR.

Target users and nursing lab context. The target audience includes teachers and students who are involved in the fundamental nursing lab course offered at Arab American University. The course is offered in the first year, second semester, along with another obligatory course titled "fundamentals and health assessments" in the nursing undergraduate program.

In the selected course, students perform practical procedures using mannequins and other models in nursing labs at Arab American University. The learning materials and manuals for the lab were prepared based on the lab's textbook [38], which contains detailed explanations and justifications related to procedures and in-depth step-by-step instructions for the procedures. Each lab procedure is given in a separate session. During the session, the nursing instructor will give brief information about the procedure and demonstrate how to perform the procedure. After that, the instructor asks the students to start performing the procedures on mannequins or any other available models. Finally, the instructor will evaluate the students and debrief them to check their skills and what they have learned.

The lab manual contains weekly procedures with all required details to perform different activities. Due to the project timeline limit, a specific number of procedures were selected to be developed and validated using VR technology. The selected procedures are as follows: 1) Body temperature; 2) Module2-peripheral pulse; 3) Wound drainage and specimen; 4) NG tube insertion; 5) Blood pressure; 6) Administering an intramuscular injection; 7) Transferring between bed and chair; and 8) Cleaning a sutured wound and changing a dressing on a wound with a drain. Subsequent procedures will be developed based on the knowledge and experience obtained from the initial development process by the VR team at Arab American University.

Toward achieving the objective of NursingXR, it is important to know how the teacher expects their students to use the NursingXR application in educational settings. Based on nursing instructors' initial feedback, NursingXR is expected to provide two modes for all procedures: training mode and evaluation mode:

- Training mode: This mode is considered mandatory for all procedures. This mode trains students on how to perform a specific procedure by following a series of predefined steps with the help of different hints and textual and visual instructions inside the VR environment. The training mode has no scores as it focuses on allowing the user to perform only one task at a time in a specific sequence. Procedures' tasks have been categorized into three groups: pre-procedure tasks, procedure tasks, and post-procedure tasks, so that each category has its own series of tasks. Each task leads to the next task, and each category connects to the next.
- Evaluation mode: This mode will be enabled if the students complete the training mode of its corresponding procedure at least once. This mode will evaluate the users' acquired knowledge and skills from the prior training. This mode does not have instructions or indicators of what to do, as it will score the performance of the student during the completion of the procedure. The scoring mechanism mainly depends on performing the correct sequence of tasks to complete the procedure. Finally, it will keep tracking the user's score even when the application is closed.

Hardware and software aspects. NursingXR will be designed to run on mid-range laptops and desktops commonly used by students or any affordable VR headsets such as Meta Quest 2 and Quest 3. During the development process, the developed demo versions will be evaluated using Oculus 2 headsets and controllers.

Concerning the required software for developing NursingXR, Unity Engine, OpenXR Tool, and XR Interaction Toolkit (XRITK) are adopted for the development process. Unity is a common programming engine and framework that can be used for developing VR applications. It provides built-in plugins and tools that support VR programming and development on different VR platforms and hardware. Furthermore, OpenXR and XRITK support the implementation of different interaction techniques with VR objects inside NursingXR using a wide range of VR headsets. For instance, the previous two tools provide building blocks and prefabs that allow the programmer to implement interactions inside the VR world, such as *hovering* by putting the VR headset's controller near or on top of an object, *grabbing* by using the VR headset's controller's grip button, *interacting* by clicking on the controller's trigger button, and *moving and navigating* using the VR headset's gear (thumb-stick).

Task analysis. Task analysis is considered one of the steps in the pipeline of creating VR applications, especially training ones [3]. Since this step focuses on revealing the possible interactions and tasks to be performed in nursing procedures, HTA was adopted in this study work. HTA is a systematic approach that can be used to divide complex tasks into subtasks (interactions) inside the VR application to understand how procedures' activities are accomplished accurately, safely, and properly. HTA is ideal for understanding the steps involved in using NursingXR, such as logging in, navigating between training procedures, completing interactive tutorials, and practicing skills for each procedure.

Figure 2 depicts that the first step is to login before starting to explore the different available features in NursingXR. Tasks 1.1 to 1.5 are available for the student to choose one of them. Each task has been broken down into sub-tasks to be performed. For instance, if the student selects Task 1.1 About, then they will be able to view more detailed information about the project (1.1.1 show details) or they will be able to view the project's credits (1.1.2 credits). Additionally, they will choose one of the VR Modes (1.2 select VR evaluation mode or 1.3 select VR training mode) that they want to perform the procedure in.

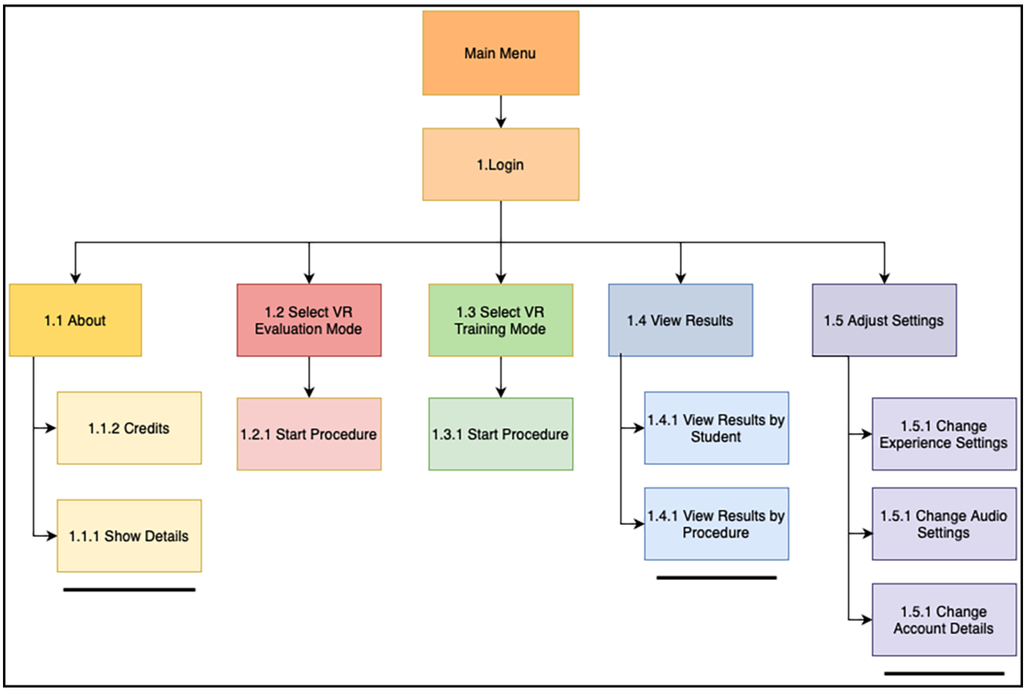


Fig. 2. Hierarchical task analysis diagram for tasks in main menu after launching the NursingXR

The HTA diagram is designed for each procedure to show detailed task analysis. The *Module 2-Peripheral Pulse* procedure was analyzed as a starting point due to its relevance to a wide range of individuals and the foundational procedure of this study. Figure 3 shows the different tasks that should be performed to complete the peripheral pulse procedure in evaluation mode. The task analysis indicates a sequential workflow composed of three main tasks sequentially: 1.2.1.1 perform pre-procedure tasks, 1.2.1.2 perform procedure tasks, and 1.2.1.3 perform post-procedure tasks. Each main task is further subdivided into subsequent tasks. The initial task is to complete all steps in pre-procedure so that the user should read instructions given on the wall, pickup clipboard, and identify themselves and patient names, wash their hands, and wear gloves. After that, the user performs the specified tasks for this procedure, which are putting fingers on the patients' wrist, holding it for 15 seconds, and recording the measurements to the computer beside the patient's bed. Lastly, performing the post-procedure tasks, including removing gloves and disposing of them, sanitizing the hands, registering the obtained measured pulses on the clipboard, and exiting the room. Exiting the room task is considered as the end point for this procedure as depicted in Figure 3 by inserting a line underlying the related rectangle.

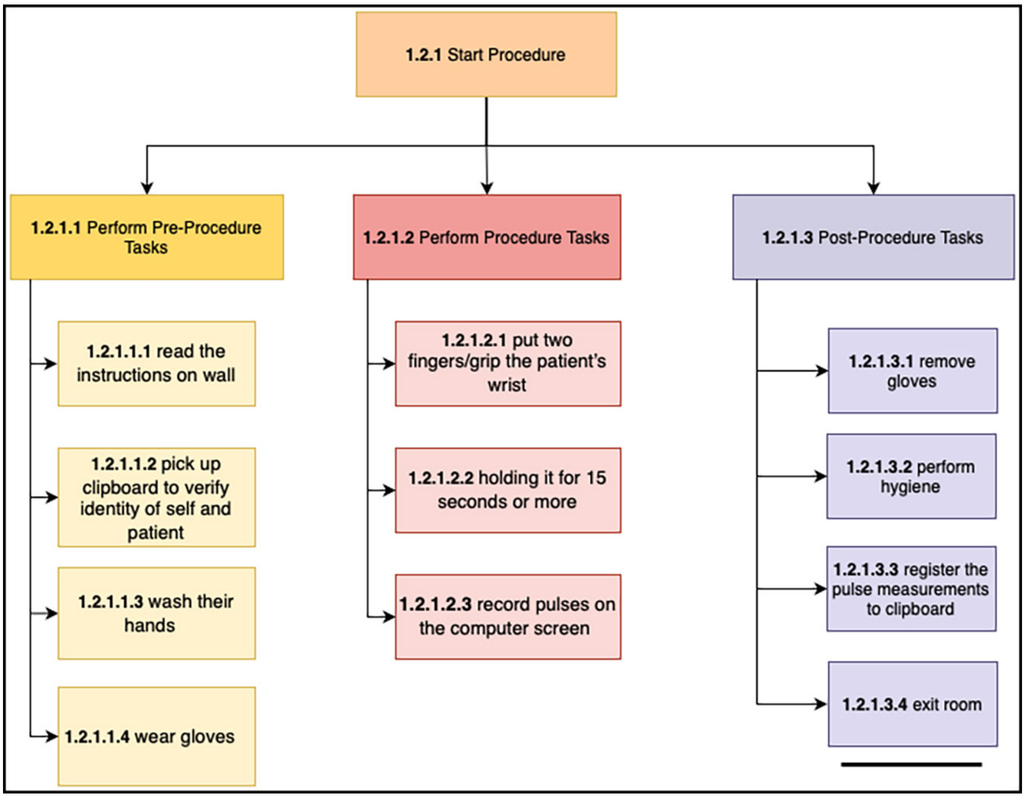


Fig. 3. Decomposition diagram for peripheral pulse procedure in evaluation mode

Design and functional requirements. Based on identified HTA for each procedure, a number of design requirements (DR) have been compiled as follow:

- DR1: Provide an intuitive interface and be user-friendly with clear instructions and tutorials.
- DR2: Should be realistic and accurately represent different nursing procedures to enhance learning outcomes.

- DR3: Consider haptic feedback (touch simulation) for specific scenarios if feasible.
- DR4: Feedback and instructions should be displayed graphically and aurally during and/or after completing procedures to enhance the immersive learning experience.
- DR5: Training mode and evaluation mode should be available for students to acquire the required skills of each procedure.
- DR6: Both security and privacy should be implemented to ensure the security and privacy of student data within the NursingXR.

Functional requirements (FR):

- FR1: NursingXR Lab should provide easy to use interface to access the different available functionalities. (*DR1*)
- FR2: Users should be able to log in to NursingXR Lab using username and password. (*DR6*)
- FR3: Each procedure should provide clear training objectives and step-by-step instructions with interactive elements, medical equipment, etc. (*DR5*)
- FR4: NursingXR lab should integrate virtual patients with different symptoms and responses depending on defined scenario-based training for each procedure. (*DR2*)
- FR5: NursingXR Lab should provide feedback mechanisms and performance evaluation based on predefined criteria to guide student's skills improvement. (*DR3*, *DR4*)
- FR6: Technical support should be available to assist users with any issues or challenges encountered while using the NursingXR Lab. (*DR1*)

The previous technical details obtained from the concept and analysis phase serve as a foundational basis and input for the design phase and collecting data and material phase. This helps VR designers and programmers to determine the appropriate UML diagrams, 3D contents, audio and video resources, and interactive elements necessary to populate the intended VR solution.

3.2 Design phase

This stage is related to understanding the sequence of steps and tasks performed inside the NursingXR and UI and UX, such as the initial mockup [12]. This stage produces the user journey and flow of tasks inside the NursingXR and initial graphical user interface. Accordingly, the proposed approach in this work suggests the identification of a use case diagram, an activity diagram, and a deployment diagram for each lab procedure. Previously mentioned UML diagrams break down and identify the sequence of activities that should be performed by the user in each procedure and determine the interaction between the students and the NursingXR and required software and hardware to make a procedure run properly.

While UML diagrams offer benefits in understanding the functional flows within the NursingXR, they have limitations in understanding aspects related to UI/UX for VR applications in general. Therefore, UML diagrams should be combined with other methods such as low fidelity prototypes (initial mockup and graphical user interface) for a more comprehensive understanding of the UI/UX and as an initial validation. However, for the NursingXR project, a different approach was adopted: rapid prototyping with high-fidelity prototype. This is due to the fact that this study opts for a more realistic and user-centered feedback of the VR experience and more valuable insights compared to low fidelity prototype. This is considered due to three reasons. First, VR technology has limited integration into a few numbers of courses and is yet widely adopted as a teaching method in Arab American University. Second, this study seeks more realistic and user-centered feedback of the VR experience and more valuable insights compared to low-fidelity prototypes. Also, the nature of VR technology as a complex interactive virtual environment that cannot be presented in a static mockup. Finally, due to the availability of both human resources (VR experts, designers, and developers) and financial resources, it was possible to manage the production of a rapid prototype with some core functionalities for one of the intended procedures (*Module2-Peripheral Pulse*). This enabled initial user testing and feedback on the core UI/UX of the NursingXR Lab. More details about the developed rapid prototype can be found in Section 4.1.

Unified modeling language diagrams. In order to have a conceptual understanding of NursingXR Lab structure and functionalities, this section identifies the possible tasks and interactions between both students and NursingXR Lab using UML diagrams. The UML diagrams presented in this section will not cover tasks and activities related to login, main menu, etc. Our criteria in UML diagrams focus on the students who have credentials to access NursingXR Lab. The used diagrams are the use case diagram (static model), activity diagram (dynamic model), and component diagram (physical model). The provided three types of diagrams cover the three kinds of UML modeling to have a comprehensive view of the system [39].

Based on our assumption in Section 3.1.3, the presented UML diagrams will depend mainly on *peripheral pulse procedure*. Therefore, the three diagrams will focus primarily on the previous procedure.

Use case diagram. The purpose of a use case diagram is to describe the possible functionalities (actions) that NursingXR enables an actor (students) to do. The actor is an entity that interacts with possible provided functionalities. Each function provided by the system is represented by an ellipse containing the name of the functionality. Distinct functions are connected by either *include relationship* (represented by a dashed arrow with an open arrowhead pointing from the base use case function to the included use case function. The label associated with this arrow is typically "include") or *extend relationship* (represented by a dashed arrow with an open arrowhead, but it points from the extending use case to the base use case. The label associated with this arrow is typically the "extend").

The use case diagrams show different functionalities after entering the room so that the user will be able to conduct all possible functions in each procedure phase (pre-procedure, procedure, and post-procedure). The use case diagrams for NursingXR might have some overlap but should not be entirely similar for both training mode and evaluation mode. To distinguish between the use cases for peripheral pulse procedure as a training mode or evaluation mode, Figure 4a shows the use case for training mode and Figure 4b shows the use case for evaluation mode. The difference between them depends mainly on the relationship between the tasks (include and extend).

As shown in Figure 4a, the student will be able to do the different available functions in each phase of the procedure. For instance, the student will be able to read the instructions from the board, pick up the clipboard, do self and patient identification, wash hands, and wear gloves. Previous functionalities are available in pre-procedure. Similarly, they are also able to perform functions related to procedure and post-procedure phases.

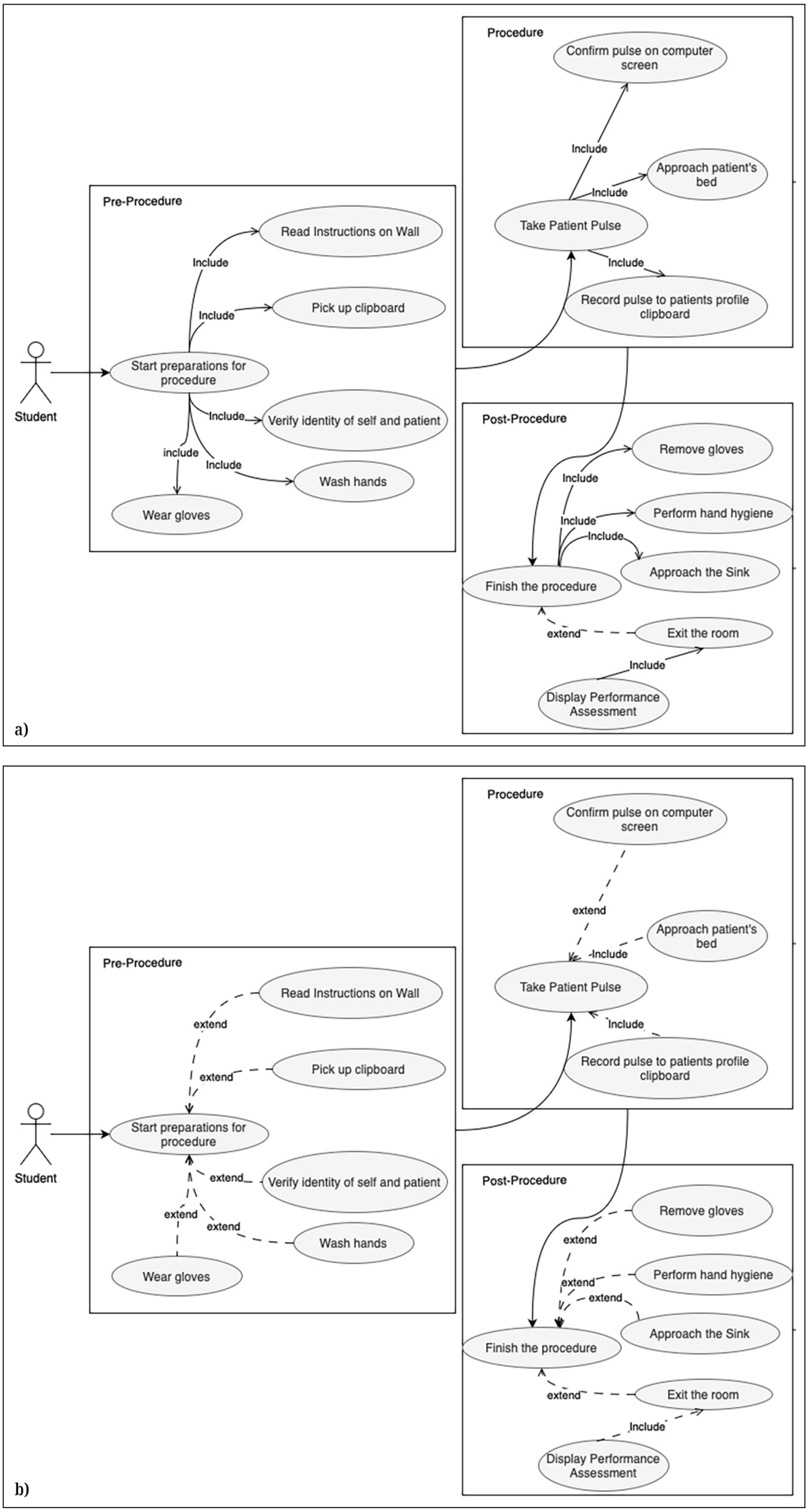


Fig. 4. Use case diagram for peripheral pulse procedure for both training mode and evaluation mode

Activity diagram. The purpose of the activity diagram (see Figure 5) is to present the activities that can be performed by the user in the *peripheral pulse procedure*. It shows the flow of activities such as entering the room, reading instructions for the procedure, etc. The initial state (represented by a solid circle) is connected to the first activity in the activity's sequence (enter the room). An activity is represented by a rounded rectangular shape. Finally, the activity diagram is ending at a final state (represented by a circle containing another solid circle) which is connected with the last activity in the *peripheral pulse procedure*. As activity diagram is a dynamic model, it can show different paths of activities between training and evaluation modes so that the pulse vibration value should be displayed based on the mode.

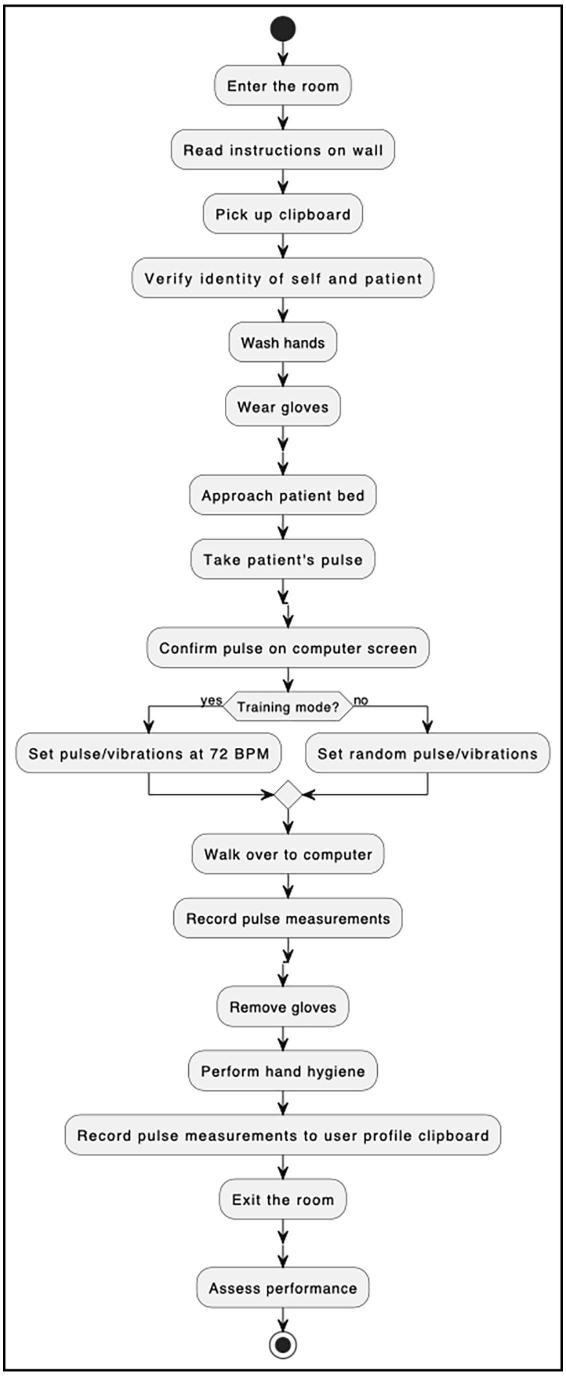
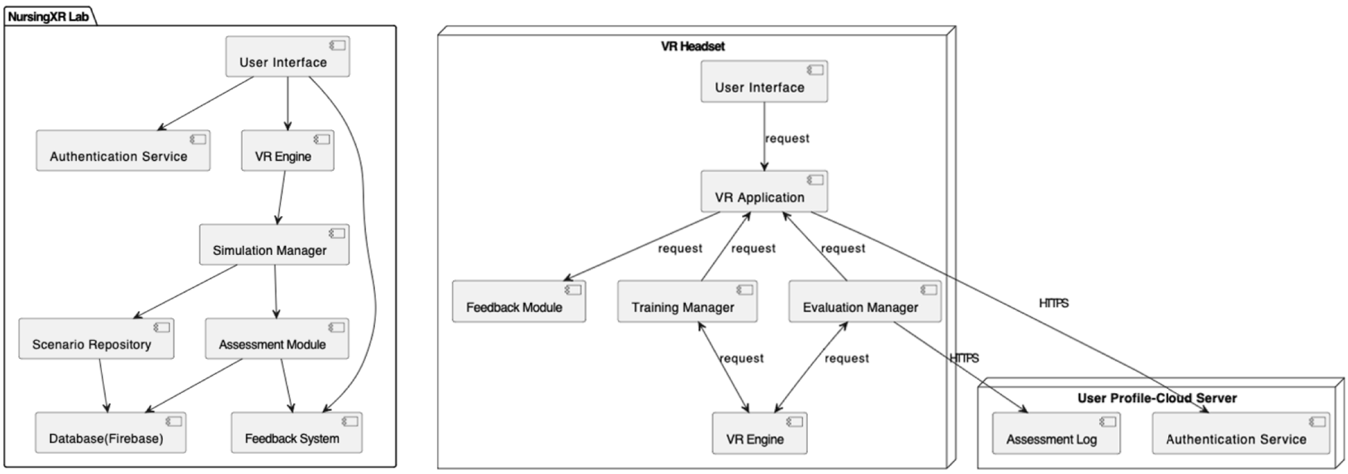


Fig. 5. Activity diagram for peripheral pulse procedure

Component and Deployment Diagrams. Both component and deployment diagrams are used for presenting the physical deployment of software development of NursingXR using different nodes, software, middleware, and hardware devices. Both diagrams can give a clear understanding of the system architecture. The component diagram (see Figure 6a) shows the primary components of NursingXR such as the user interface, VR engine, etc. It focuses on the possible interactions between different components, ensuring modularity and ease of maintenance. The deployment diagram (see Figure 6b) shows how these components are physically deployed across various hardware nodes. The two main nodes (devices) are VR headset and the cloud server. The VR headset can be one of standalone devices such as Oculus Quest 3, HTC VIVE, etc. The utilization of cloud services such as firebase or photon is for user profile management. This deployment design ensures robust performance and scalability, essential for delivering an immersive and effective nursing training experience.



a) Component diagram **b) Deployment diagram**

Fig. 6. Component and deployment diagrams

3.3 Collecting data and material phase

This phase focuses on preparing the various multimedia assets that will populate the distinct parts of procedures in NursingXR. The result of this stage is an asset repository including multimedia assets (3D materials, audio, video, etc.) and required animation resources. Such results will be required for consequence phases (assembly and testing phases in MDCL).

Given the indoor setting of nursing procedures, NursingXR has a 3D environment (scene) where all procedure tasks happen. This 3D environment includes spatial distribution of different media and art assets such as avatars (characters representing patients, nurses, physicians, players, etc.), 3D models, videos, audio, and animation sequences attached to 3D models.

First, the 3D environment (scene) is considered the first big asset that represents the nursing room where students perform the nursing procedures. To enhance user immersion, the nursing room background is designed to resemble an actual nursing lab, including patients, medical equipment, etc. Additionally, recorded ambient sounds from real nursing rooms are incorporated into the background to create a realistic nursing environment to engage students in the nursing procedures. To do so, it was recreated using photography of a real nursing lab at Shenandoah University, where nursing students perform nursing procedures.

Second, identification of media assets (which populate the VR environment, such as 3D objects, images, sound files, video files, etc.) is performed in this stage of the development methodology (MDCL). Also, for each asset, it was important to determine the procedure that will be included. To avoid reinventing already existing assets, the status of assets is added to the list (refer to Table 1). The status value can be one of the following: *available, available-required customization, production needed,* and *texture needed*. This list is used by VR programmers and 3D modeling to start preparing the required assets for different procedures.

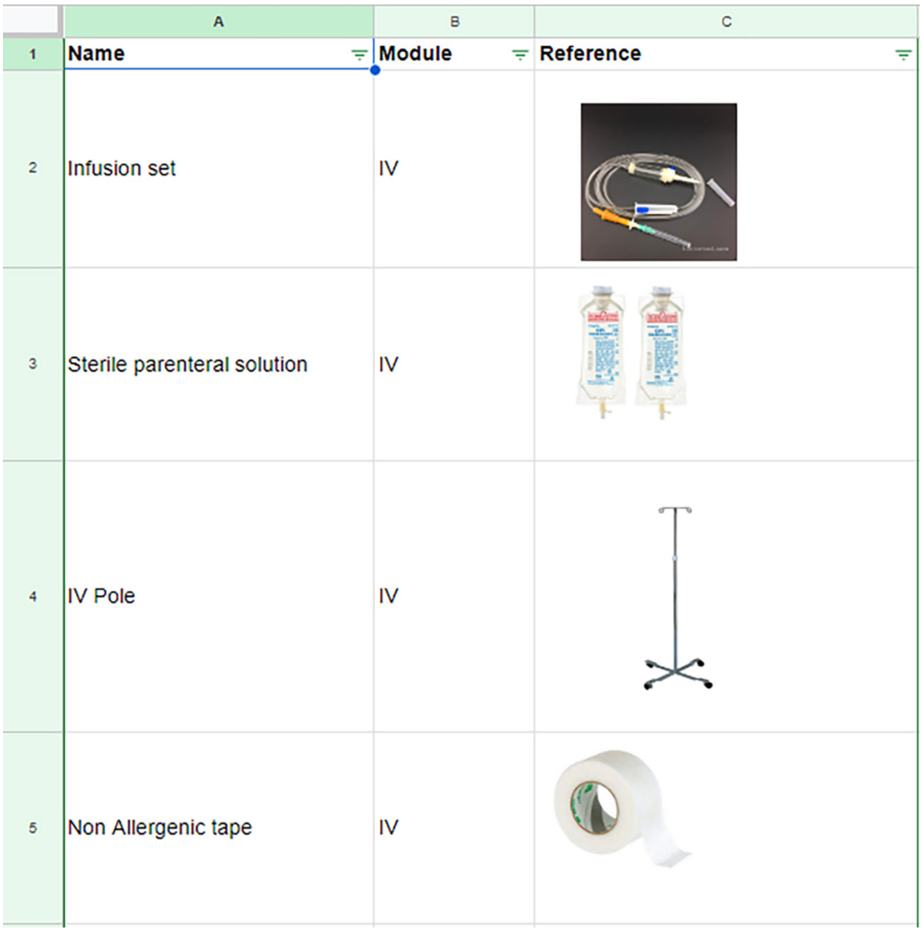
Table 1. List of assets identifications sample

Name	Type	Module	Status
Infusion set*	3D Model	IV	Production needed
Non-allergenic tape	3D Model	IV	Production needed
Gloves	3D Model	IV, UCath	Available
Tourniquet*	3D Model	IV	Production needed
Antiseptic swabs	3D Model	IV, Blood Pressure	Available-required customization
Splint	3D Model	IV	Texture needed
Fluid through prime tubing	Animation	IV	Production needed
Hear beating	Sound	Peripheral pulse, IV	Available
Patient Identification	Sound	All procedures	Production needed

After preparing the asset list, the creation process is started for each different asset. Some assets were available as open-source files and have been considered in this step. Selection criteria for the available online resources were based on the accurate representation of the asset and low polygon count. Furthermore, due to a sizable number of developed VR projects in the Shenandoah Center for Immersive Learning (SCiL) at Shenandoah University, it was possible to reuse 3D objects available from previous projects. Modifications were made to 3D models that were identical matches to real-world objects so that no infringements were made inadvertently. Several models were created in this way such as thermometers, germicidal wet wipes, the nasogastric tube, towels, etc.

Third, all the required animations of 3D objects were implemented by VR programmers, as it is not easy to find available 3D objects attached to the required animation. For instance, the animation of an avatar patient's flexing up their hands when a student (player) approaches them to start recording the pulse measurements was implemented from scratch by the VR programmers.

Finally, the output of this phase is a list of produced assets compiled inside a spreadsheet file, including a reference to the resource file for each asset (see Figure 7). All files are stored inside a designated online folder for the project.



	A	B	C
1	Name	Module	Reference
2	Infusion set	IV	
3	Sterile parenteral solution	IV	
4	IV Pole	IV	
5	Non Allergenic tape	IV	

Fig. 7. Produced asset spreadsheet

4 RESULTS

As a result of this study work, a rapid prototype and formative evaluation were conducted to validate the proposed approach. Next subsections provide a detailed description of technical details related to the developed prototype and about obtained feedback from instructors who evaluated the NursingXR prototype.

4.1 Rapid prototyping

The idea of this rapid prototyping is to implement one of the identified procedures with its main functionalities based on reports and documents obtained from previous phases (analysis, design, and collecting materials). To develop the rapid prototype effectively, a white-box approach was employed to implement core interactions and functionalities of NursingXR before adding all required assets for each procedure. The white-box approach enables VR developers from the two project's partners to build and implement the system's logic and structure collaboratively, as multiple developers are able to work on different components of the prototype with a shared understanding of the underlying architecture. After completing the white-boxing process and adding all required assets for the procedure, the two parts were combined and migrated to make a mostly complete module.

The rapid prototyping was applied to the peripheral pulse procedure by adding all assets to the procedure scene and adjusting the interactions to ensure that the procedure is working properly. Different bug fixes were performed to make sure that the procedure is ready for deployment in VR headsets such as Quest Pro and Quest 2. The developed prototype is used to obtain preliminary validation for the proposed hybrid development approach and feedback from nursing instructors.

Unity engine and C# based-script were used to implement peripheral pulse procedure prototype with its functionalities and interactions. Furthermore, socket interactor techniques provided by Unity3D facilitated the implementation of intuitive interactions and triggering for animation attached to 3D objects. Concerning 3D modeling tools such as Maya, Blender, and SketchUp were used to create assets required for the targeted procedure.

In the pre-procedure phase, the activities are as follows: student enters room, reads the instructions on wall related to the procedure (see Figure 8a), picks up clipboard to verify identity of self and patient, washes their hands (see Figure 8c), and wears gloves (see Figure 8d). The user can navigate either via smooth locomotion or teleporting navigation (see Figure 8b).

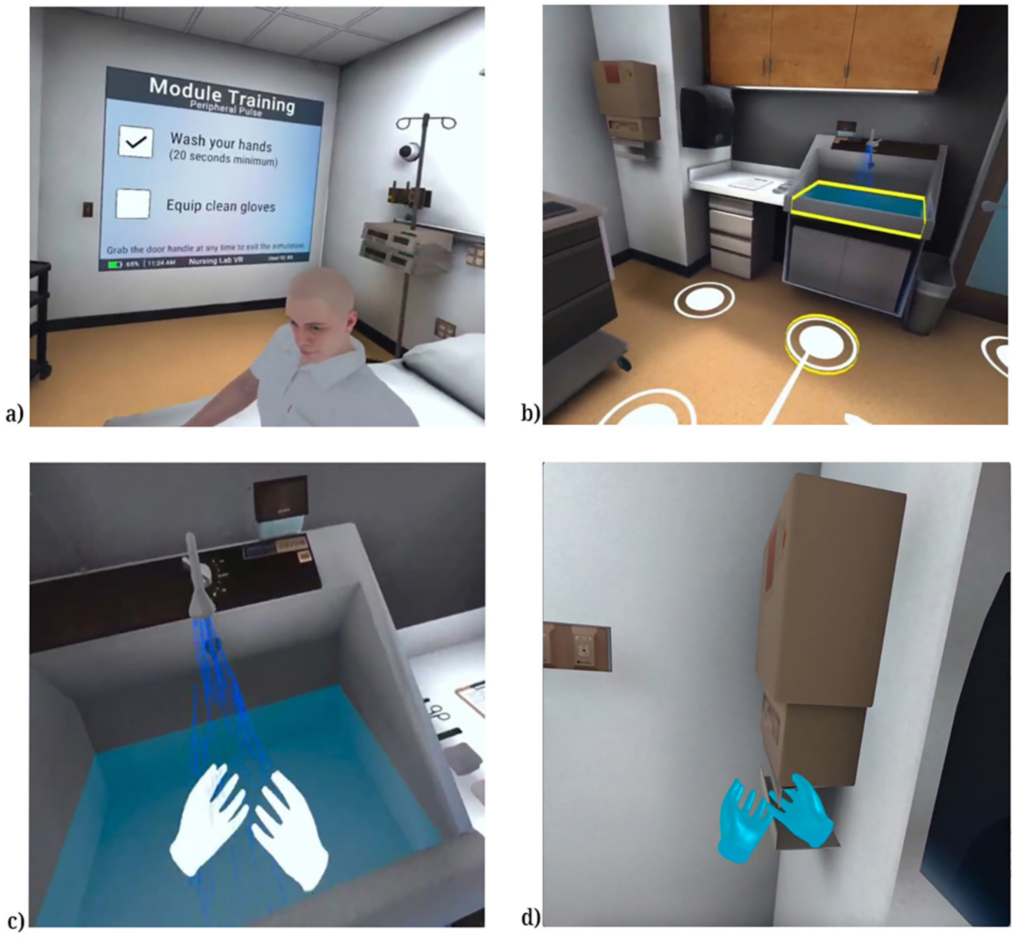


Fig. 8. Pre procedure activities (read instructions on wall (a), teleport to washing sink (b), and wash hands (c), wearing gloves (d))

After completing the pre-procedure, the NursingXR prototype will show a new list of instructions to be performed during the training mode of the procedure. For instance, the user is asked to put two fingers/grip the patient's wrist to feel his pulse and hold it for 15 seconds or more (see Figure 9a). Then the user is asked to confirm this pulse on the computer screen beside the bed (see Figure 9b), thus completing the module (training mode or evaluation mode).

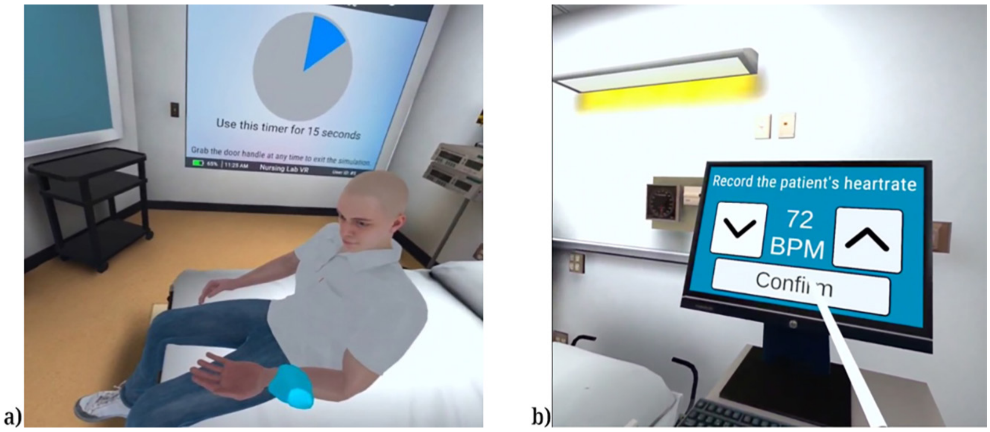


Fig. 9. Taking pulse measurements and recording them into the computer

From a technical perspective, when the user approaches the patient's bed, an invisible box is defined to specify the area that the student should be inside it to be in the proper position for taking the patient's pulse.

After that, the patient will put their hand up in a realistic way to take the pulse. During taking a pulse, it was programmed that haptics within the controller start vibrating based on set values. The set values are defined depending on the chosen procedure's mode (training or evaluation). For instance, if the user is performing the procedure using training mode, the pulse/vibrations are set at 72 beats per minute (see Figure 10a). On the other hand, if the user is in the evaluation mode (see Figure 10b), the pulse/vibrations are set to be a random one of 10 different values {52, 60, 68, 72, 76, 80, 84, 88, 96, 104} in the evaluation mode.

After taking the patient's pulse, similar to the implemented technique in approaching the patient's bed, the student should walk over to the computer beside the patient's bed. An invisible box is defined to specify the position that will turn on the computer screen so that the student records the pulse measurements.

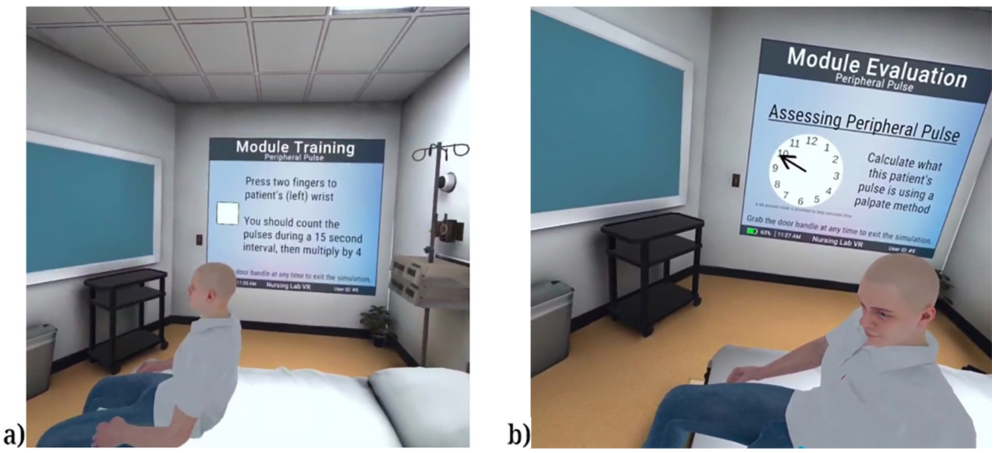


Fig. 10. Instructions to perform peripheral pulse

Finally, once the student completed the required activities and tasks related to the procedure, they should remove gloves, perform hand hygiene, record the pulse measurements to the user profile clipboard, and exit the room. Once the student reaches the door, they will be able to see assessments of their performance on the door (see Figure 11). This will end the procedure and return the student to the main menu so that he can perform other procedures.

Fig. 11. Showing obtained results after performing the procedures

4.2 Formative evaluation

Formative evaluation is known for getting information about the design process. Therefore, to ascertain if the developed VR prototype meets the identified analysis and design requirements and ensure the quality and functionality of NursingXR before starting the experiment with students, a study with teachers has been conducted. This is based on highlighted aspects in [40], [41], such as the need for a domain expert to asset VR solutions to provide qualitative feedback on strengths and weaknesses to have a more holistic evaluation.

First, eight teachers from the nursing department who teach the fundamentals of nursing lab at Arab American University were given a 10-minute demo about using Oculus Pro headsets inside the VR lab at Arab American University. After that, the teachers were asked to start using the NursingXR application that was installed in the VR headsets and follow the instructions in training mode and perform the required tasks in evaluation mode for the peripheral pulse procedure. Finally, the teachers were asked five open-ended questions to get their opinions about their experience using NursingXR. The teachers were asked to write their answers after each question.

The teachers answered the question, "Q1) Do you think NursingXR facilitates your teaching Nursing Lab?" with positive feedback and appreciation comments (see Figure 12a). Two teachers mentioned that NursingXR can improve learning outcomes. Three teachers ensured that this technology was helpful in the teaching process. There were three comments that mentioned that the immersive feature can be interesting for students. For instance, one of the answers was "*help to put the students in the atmosphere of a real situation before the real clinical experience*."

To seek more details concerning teaching nursing labs using VR, teachers are encouraged to answer the question "Q2) Why do you think NursingXR is helpful?

In what areas does the tool help you?" As shown in Figure 12b, four teachers pointed out the safe environment for the students since there will not be a risk to the patients or nursing students. Three teachers mentioned that NursingXR can be considered a complementary tool for classical teaching and four teachers considered it useful, especially during distance teaching and learning. Previous claims were based on their belief that having enough time for performing rehearsals for procedures is regarded as one of the facets of time constraints in real nursing labs. NursingXR allows for repetitive practice to identify their strengths and weaknesses and overcome limitations in traditional skills labs.

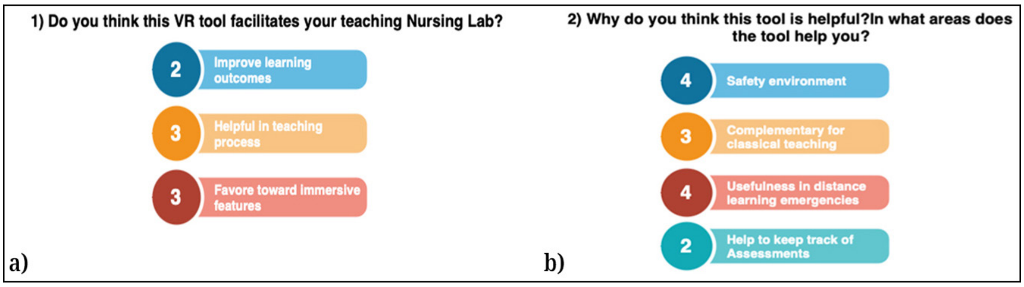


Fig. 12. Teacher's response to Q1 and Q2

Concerning the teachers' response to the question "Q3) How does NursingXR compare with other learning tools you have used, such as flash applications and 3D learning software, for which you use a mouse to interact with the computer?", all of them agreed that the VR tool is more helpful compared to other tools. Based on the comments, this is due to two reasons. First, five teachers think that VR tools can help students to improve their skills by practicing them anytime and anywhere, having cases such as real clinical cases. Furthermore, it was mentioned that using a computer causes staying for a long time without performing movements. Second, there were remarks related to richer interactivity in VR tools (see Figure 13a).

As a step to acquire disadvantages noticed in the VR tool, teachers are asked to answer "Q4) Do you think that NursingXR has disadvantages? What are they?" Most of the comments were related to technical issues (see Figure 13b). For instance, five teachers noticed that there was a latency between the controllers and NursingXR, and they had internet connection disruption during the experiment. The other two teachers mentioned that the lack of psychosocial aspects in NursingXR is considered a disadvantage.

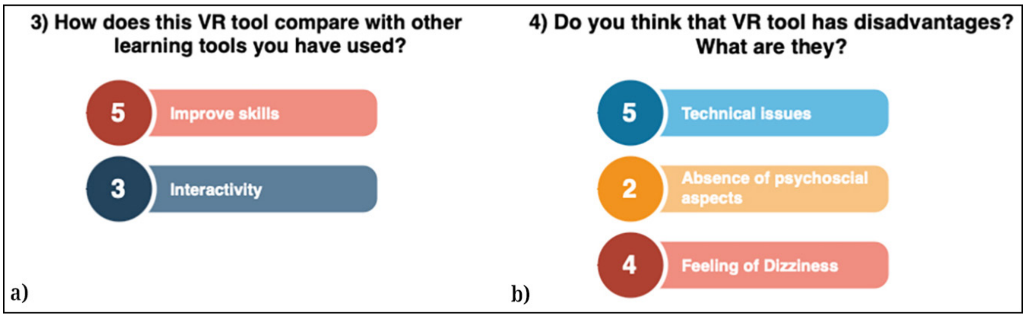


Fig. 13. Obtained feedback from teachers concerning Q3 and Q4

As for advising to improve the VR tool "Q5) Can you offer some advice for improving this NursingXR?", the collected remarks were divided into three categories as shown in Figure 14. First, three teachers stressed the need for enough training time for students to be able to use the VR tools and hardware properly. Second, four teachers were able to perform the experiment with some difficulties. Therefore, they believe that the NursingXR should provide more helpful instructions related to how to use VR headsets and their controller before starting the procedures. It was noted that they had the feeling of dizziness while using smooth locomotion navigation while performing the experiment. More favor toward the teleporting technique was notable. Other comments were related to providing voice instructions along with instructions on the wall. Third, one teacher suggests having a similar VR application for other courses such as adult nursing, pediatrics, rehabilitation, and ER.

Fig. 14. Collected advice concerning NursingXR

5 DISCUSSION AND RECOMMENDATIONS

The result of developing the NursingXR prototype and the feedback obtained from instructors validate that the proposed hybrid approach helps to effectively integrate VR technology in nursing courses and labs. This study utilized both HTA as a complementary step in the concept and analysis phase and UML in the design phase of the MDLC. The proposed hybrid approach was explicitly derived, unlike previous research [40], [18], [19], [20], [22], which primarily focused on either HTA or UML for design and development.

By combining both methods, this approach supports the fulfillment of design and functional requirements by understanding user needs, tasks, application context, and the early identification of required 3D models, assets, and interaction techniques.

Regarding the use of HTA in developing VR applications, prior studies [41], [42] highlighted certain limitations in traditional HCI approaches, particularly HTA, when applied to VR development. For instance, [42] pointed out that task analysis can be challenging when identifying meaningful tasks and intended users in VR environments, as well as conducting iterative development. However, this study demonstrates that integrating HTA into MDCL facilitates effective task analysis of various procedures related to nursing labs. The results validate that HTA can formalize a task description, providing a detailed breakdown of complex patterns within nursing lab procedures. This breakdown can be invaluable for VR developers as it offers a clear sequence of tasks, assets, and resources required to develop NursingXR.

Similarly, there have been limited attempts to adopt UML for VR development, yet this study highlights its usefulness in structuring VR applications. For example, [23] applied UML to develop a VR application for flood disaster management, while

[25] used it for a VR platform that helps students learn programming concepts. Expanding on these studies, this work explored UML's potential in the healthcare domain. UML diagrams, integrated with MDCL, clearly define relationships between users and their roles, offering a comprehensive insight into the user experience in VR applications for healthcare. These diagrams also help VR programmers write the corresponding code for each functionality. In the case of Nursing XR, UML was particularly helpful in creating dynamic, varied simulation scenarios for different heart rates during the evaluation mode of the peripheral pulse procedure.

The feedback from nursing instructors during the evaluation phase provided several recommendations, including a preference for the use of teleportation as an easier navigation technique compared to smooth locomotion in NursingXR [43]. This was largely due to some teachers experiencing dizziness when with smooth navigation. Additionally, the results revealed a need for more training and tutorials to help teachers and students become more familiar with VR technologies.

In terms of long-term impact, integrating VR solutions such as NursingXR into nursing education could transform how clinical skills are taught and reinforced over time. VR offers the potential for students to repeatedly practice essential nursing procedures in a controlled and risk-free environment, leading to improved retention and skill mastery. By incorporating VR, institutions can provide consistent, scalable, and standardized training experiences, which is especially valuable in addressing the challenges posed by varying levels of access to clinical settings. Over time, VR applications can also evolve to simulate complex medical scenarios, allowing students to encounter a broader range of clinical cases that might not be available in traditional lab settings. As the technology continues to advance, particularly with the integration of artificial intelligence and adaptive learning techniques, VR platforms could personalize the learning experience for each student, further enhancing their competence and preparedness for real-world healthcare environments.

While the white-boxing approach enabled early testing and initial feedback, a more comprehensive usability testing phase with a larger sample of nursing students is necessary to validate the system's effectiveness and identify areas for improvement related to UI or UX in terms of ease of use, clarity, and usefulness. One limitation of this study was that only a single procedure (peripheral pulse) was used to establish the feasibility of the proposed approach. A broader range of procedures would provide a more comprehensive assessment. While the technical aspects of VR development were thoroughly explored, the study did not delve deeply into the educational implications or learning outcomes associated with using NursingXR.

6 CONCLUSION AND FUTURE WORK

This study proposed a task-centered methodology for developing a VR solution, utilizing both HTA and UML in the initial stages of the MDCL. With its robust foundation and improved understanding of task sequences and user experience, the proposed approach assists developers in building VR solutions for nursing labs. Two validation steps were performed to assist the approach. The first step involved developing a rapid prototype based on the early stages (analysis, design and material/data collection phases). The second step was an initial user study with nursing instructors to gather feedback on the effectiveness of the proposed approach in developing and integrating NursingXR into the fundamentals nursing lab given at Arab American University. Based on the positive results from these steps, the proposed hybrid approach was deemed valid. The research achieved technology readiness levels: TRL1, TR2, TRL3, TRL4, and TRL5 [44], with TRL6, TRL7, TRL8, and TRL9 expected to be achieved once the final version of NursingXR is developed. This highlights the importance of the task-centered approach in the analysis phase of the VR health educational systems development. Additionally, the results have led to updates and improvements, shedding new light on several functionalities and user experience aspects in the final version of NursingXR.

For future work, a study will include students as end users to gather feedback on UI/UX requirements for NursingXR. This will provide valuable insights into the system's effectiveness, usability, and areas of improvement from the users' perspective. Efforts will also be made to enhance NursingXR to support a collaborative environment that simulates a traditional classroom and lab. The upgraded version of NursingXR, featuring a multiuser environment, can be integrated with metaverse platforms. Such an environment may increase cognitive load for students, and thus different versions of NursingXR compatible with desktop or laptop devices, as seen in previous studies [33], will be developed to compare the effectiveness between HDMs and desktop or laptop devices, ensuring NursingXR is accessible to a wide range of students.

With the rising demand for utilizing AI across various domains and the rapid evolution of AI and algorithms, there is potential to explore the usefulness of AI for dynamic generation of 3D contents, haptics feedback, adaptive patient conversations and scenarios, or eye tracking to further enhance the VR experience in the healthcare domain.

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