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Integrating Procedural Information into XR Simulation for Basic Life Support Training

Daeun Kim[1] and Jeeheon Ryu[1]

[1] Chonnam National University, Gwangju, South Korea
jeeheon@jnu.ac.kr

Abstract. This study proposes a design case for developing procedural information in extended reality (XR)-based Basic Life Support (BLS) training simulations, focusing on integrating immersive learning environments to align with XR-specific features. Procedural information was developed using the 4C/ID model, incorporating demonstration, just-in-time information, and corrective feedback were incorporated to support learners in effectively acquiring and automating BLS skills. Demonstrations provided visual and auditory guidance for observing task execution comprehensively, while just-in-time information offered step-specific procedural rules to facilitate cognitive integration during task performance. Corrective feedback enabled learners to identify and address errors, ensuring accurate procedural execution. The simulation emphasized spatial interaction and engagement to provide learners with authentic and immersive practice experiences that bridge theoretical knowledge and practical application. Expert reviews and iterative pilot testing refined the design, enhancing usability and instructional effectiveness. This study highlights the importance of procedural information design in creating XR-based simulations that promote learner engagement and skill acquisition. Future research should explore the effectiveness of multimodal interaction and specific XR design features in supporting cognitive and procedural learning outcomes, aiming to optimize knowledge retention and transfer across diverse educational contexts.

Keywords: XR Simulation, Procedural Information, Basic Life Support (BLS) Training.

1 Introduction

Simulation-based learning in healthcare allows learners to repeatedly practice medical skills and procedures in a safe and controlled environment [1]. Due to the high risks and potential medical errors in healthcare practices, simulation has become one of the essential learning tools [2]. Healthcare simulations replicate complex procedures and scenarios in a way that closely procedures that resembles real-life conditions, allowing learners to experience a variety of scenarios in advance, thereby facilitating the effective transfer of knowledge and skills to real-world contexts [3]. Extended reality (XR)-based simulations combine virtual elements with physical environments, enabling learners to perform in realistic settings while promoting interaction and providing appropriate instructional support to learners.

In the healthcare sector, extensive research has been conducted on simulation-based learning, and various simulation design guidelines have been proposed [4-5]. However, these guidelines primarily focus on the specialized knowledge or content aspects of simulations and tend to emphasize the instructor's role in the design and implementation process rather than centering on the learner's experience [6]. The ultimate goal of healthcare simulation education is to enable learners to effectively apply the knowledge, skills, and attitudes they have acquired to new clinical situations. Achieving this goal requires the application of pedagogical instructional models that go beyond traditional knowledge-centered design and thoroughly address learners' cognitive needs [3]. Based on this approach, the design of XR-based healthcare simulations can provide immersive learning environments that effectively support learners in acquiring transferable knowledge and skills for real-life applications.

Cardiac arrest is a life-threatening condition that can occur suddenly and without warning, leading to the complete cessation of heart function. It is a significant cause of death worldwide, with thousands of cases reported each year [7]. In light of this, healthcare students and the general public must be familiar with the Basic Life

Support (BLS) process, which involves administering chest compressions to restore blood flow and oxygenation in the body [8]. Knowing how to perform BLS can make a significant difference in the outcome of cardiac arrest and potentially save lives. One of the key features of BLS training is its standardized procedures and protocols. Therefore, providing appropriate procedural information to facilitate learners' schema automation is essential in BLS training simulations. This study proposes effective procedural information design strategies for XR-based healthcare simulations in BLS training. The 4C/ID model was applied for structuring simulation design, and a formative design process was undertaken, carefully considering the characteristics of XR learning environments.

Literature Review

When applying task-centered instruction (TCI) principles, simulation-based learning supports learners in integrating theoretical knowledge and practical skills by solving complex tasks in realistic environments [9]. TCI emphasizes transferring learning by allowing learners to apply acquired knowledge directly to tasks or problems closely mimicking real-life scenarios [10]. The 4C/ID model is an instructional design framework that effectively implements TCI principles, focusing on facilitating learning transfer through complex tasks and problem-solving [11]. Complex learning is the integration of knowledge, skills, and attitudes, coordination of qualitatively different constituent skills, and application of what is learned in real-life and work environments [11]. Initially used for technical domains like programming and pilot training, this model has since expanded to fields such as healthcare, teacher education, and vocational training [12-13]. The 4C/ID model has proven to be a practical approach to instructional design by systematically designing complex tasks and supporting learner competency development.

Procedural learning focuses on enabling learners to flexibly apply acquired knowledge and skills to new situations, promoting learning transfer [14]. According to the 4C/ID model, this transfer is facilitated by schema construction and automation [11]. Procedural information is vital in helping learners form cognitive rules for tasks and build long-term memory structures to support automation. Presented as accessible, independent units, procedural information guides learners through tasks and is often provided via job aids, instructor guidance, or other support tools. In XR environments, procedural information enhances learner engagement and interaction, serving as a critical design component. [15] highlighted certain characteristics of XR-based procedural learning, like repetitive practice, record verification, and timely feedback, that are instrumental in transforming theoretical knowledge into practical expertise. Consequently, exploring the design and application of procedural information in XR environments is essential for creating effective learning solutions and establishing an empirical foundation for instructional design.

XR-based Basic Life Support Training Simulation

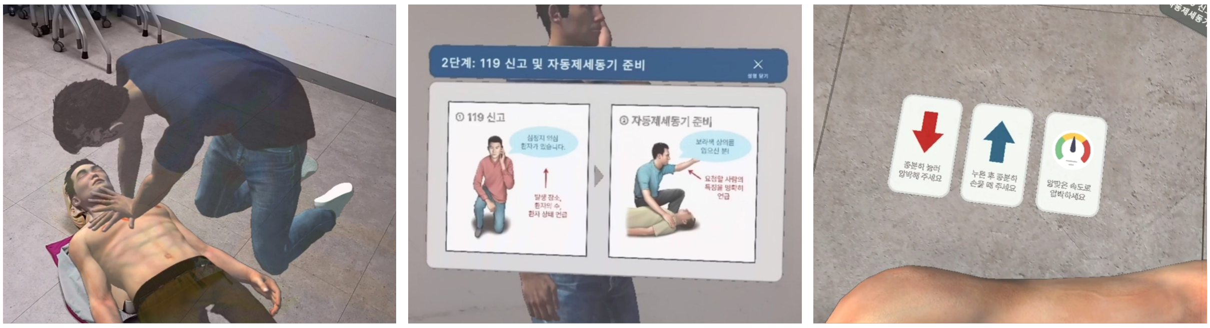
Learning Task Design. The learning task utilized in this study's simulation is Basic Life Support (BLS) performed by lay rescuers. BLS was selected as the study task due to its critical importance as a life-saving emergency procedure and its suitability for procedural learning, as it requires precise step-by-step execution [16-17]. Before designing the simulation, a procedural analysis was conducted based on widely recognized guidelines for layperson BLS. The BLS procedure includes the following steps: 1) assessing the consciousness, 2) calling emergency services and preparing an AED, 3) performing chest compressions, and 4) using an AED. Each step was subdivided into detailed actions, which served as the basis for designing learners' procedural tasks. The simulation identifies the absence of normal breathing during consciousness assessment and performs chest compressions only without incorporating additional rescue breathing procedures.

Procedural Information Design. The procedural information in this study was designed based on the instructional design principles of the 4C/ID model, incorporating demonstration, just-in-time information (JIT information), and corrective feedback [11]. Demonstration involves showing examples of how rules or procedures are applied, allowing learners to observe the correct execution of tasks [11]. For example, in "Step 1: Assessing the patient's consciousness," learners are instructed to first assess the safety of the surroundings, observe chest movements to check for breathing, and then tap the patient's shoulders firmly while calling out to assess consciousness. In the XR environment, learners were provided with visual demonstrations where a 3D agent performed the procedure as an animated sequence. Learners could navigate within the physical space and observe the agent's actions from various angles. Auditory narration and sound effects, such as tapping on shoulders, were included to enhance the demonstration. Figure 1a illustrates this implementation, showing an animated agent performing chest compressions on a virtual patient within the XR setting.

JIT information refers to the essential rules or procedures required for performing specific tasks within complex skills [11]. Each procedural step was designed as an independent unit containing only one rule or process. For instance, in "Step 2: Calling emergency services and preparing the AED," the JIT information outlined the process of calling emergency services and requesting an AED from bystanders (Figure 1b). Details such as providing the location, the number of patients, and their condition during the emergency call were explicitly stated. To help learners seamlessly integrate the information with the task execution, visual JIT information was provided in the form of infographics combining images and text. The XR environment utilized the HoloLens 2's hand menu feature, enabling learners to access just-in-time information by activating a display with a simple hand gesture. This allowed learners to check information as needed without disrupting task performance. The interactive design ensured that the information display followed the user's head movements, reducing cognitive overload and supporting seamless task execution and learning experience.

Corrective feedback helps learners identify errors in task performance and develop accurate rules and procedures [11]. For each step, performance objectives were established to assess task completion. For example, in "Step 4: Using the AED," the first objective was to turn on the AED. If the learner pressed the power button, they could proceed to the next step, "attaching the pads." However, if the wrong button was pressed or no action was taken for 30 seconds, corrective feedback such as "Please check the AED device and turn on the power" was displayed. Corrective feedback was displayed within the user's field of view for a specific duration. However, during the chest compression phase involving significant physical movement, pop-up feedback could be distracting and difficult to read. To address this, feedback during the chest compression phase was positioned next to the virtual patient in the form of a card, as shown in Figure 1c. As the simulation utilized a real mannequin, the instructor was able to assess performance in real-time and provide immediate feedback on chest compression depth, release, and speed.

After completing the simulation design, expert reviews were conducted with two PhDs in educational technology and one PhD in nursing. The reviews involved in-depth interviews assessing the appropriateness of the scenario's steps, content accuracy, and considerations for BLS training. Experts found the overall scenario design appropriate but suggested revisions to improve content accuracy. They also recommended adding a review process after the simulation and including auditory signals, such as metronome cues, to guide chest compression speed. These recommendations were incorporated to enhance the simulation's overall quality and effectiveness.



(a) (b) (c)

Fig. 1. Implementation of procedural information in the XR simulation: (a) Demonstration of chest compression by a 3D virtual agent, (b) Just-in-time information panel providing step-by-step guidance, (c) Corrective feedback using visual cues.

1.1 Development

The XR simulation utilized in this study was developed using Microsoft's HoloLens 2, an XR device. The simulation environment and system interactions were built with Unity 2020.3.27f1 and MRTK 2.8.1, while 3D characters and animations were created using Character Creator 4 and iClone 8 from Reallusion. SketchUp for School was also used to model high-fidelity 3D assets, such as AED devices and electrode pads, ensuring a realistic and immersive simulation environment. The developed simulation aimed to provide an immersive learning experience for BLS training by integrating virtual patients with physical mannequins. This allowed learners to check the consciousness of a virtual patient overlaid on a real mannequin while physically interacting with it, such as tapping its shoulder or performing chest compressions. Integrating physical engagement with digital augmentation in the simulation design promoted the creation of a deeply engaging practice environment.

Two rounds of internal pilot testing were conducted to evaluate the usability and effectiveness of the simulation and identify usability issues, user errors, and system improvement points. All evaluators experienced the entire simulation process and provided feedback after completion. During the simulation testing, the developers recorded the time taken for each task and observed whether users demonstrated the expected behaviors. For instance, when auditory and visual demonstration information was presented, the expected user behavior was to observe the agent's actions while listening to the narration. However, if a user only listened to the narration while staring straight ahead without visually engaging with the agent, this was considered a failure in expected behaviors that were categorized on the basis of their root causes, such as design shortcomings or system bugs.

The first pilot test (*N*=4) identified areas for improvement in user interface and user experience enhancements, including adjustments to the hand menu position and ensuring the appropriate distance for displays and pop-up messages. The second pilot test (*N*=6) focused on identifying and resolving system errors and bugs, improving the simulation's usability and overall performance.

2 Discussion and Conclusion

This study aimed to propose a procedural information design framework for XR-based BLS training simulations, emphasizing the integration of immersive learning environments tailored to the unique features of XR. By leveraging the capabilities of XR, such as spatial interaction and multimodal sensory engagement, the simulation provided learners with an authentic and immersive practice experience that bridges the gap between theoretical knowledge and practical application. The findings highlight the significance of designing learning environments that align with the characteristics of XR to enhance learner engagement, interaction, and skill acquisition.

Future research should focus on systematically reviewing the effectiveness of XR-based BLS simulations in achieving intended learning outcomes. This includes examining the impact of multimodal interaction on learners' cognitive and procedural skill development and exploring how specific XR design features contribute to long-term knowledge retention and skill transfer. Future studies can further refine XR-based simulation design and establish a robust foundation for its application across diverse educational and professional training contexts by addressing these areas.

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