The use of immersive virtual reality training for developing non-technical skills among nursing students: a multi-methods study

Kitty Chan, Patrick Pui Kin Kor, Justina Yat Wa LIU, Kin CHEUNG, Timothy LAI, Rick Yiu Cho Kwan

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Kitty Chan[1] PhD; Patrick Pui Kin Kor[1] PhD; Justina Yat Wa LIU[1] PhD, FAAN; Kin CHEUNG[1] PhD; Timothy LAI[1] MSc; Rick Yiu Cho Kwan[1] PhD

[1]School of Nursing, The Hong Kong Polytechnic University Hong Kong SAR HK

Corresponding Author:
Kitty Chan PhD
School of Nursing, The Hong Kong Polytechnic University
Hong Kong
Hong Kong SAR
HK

Abstract

Background: Immersive Virtual Reality (IVR) is a niche technology rising popularity in nursing education. Although there is a paucity of evidence to demonstrate the effect of VR on desired learning outcomes, this evidence is limited to technical or procedural skills or managing a single patient with clinical problems. Non-technical skills such as communications, decision making, team work, situation awareness, and managerial skills have not been explored by the IVR technology.

Objective: This study aimed to (1) investigate the potential efficacy of VR-Hospital on the students' (a) non-technical skills (b) sense of presence in the virtual clinical environment, and (c) satisfaction and self-confidence in learning; (2) identify the variables that predicted the non-technical skills; (3) explore their experience in using the IVR

Methods: A multi-methods design with quantitative and qualitative approach was adopted. The participants were provided with the IVR system (VR-Hospital) with three scenarios in the training. The VR-Hosp was a IVR game which adopted a multi-bed, multi-patient, multi-task approach and embedded with various clinical situations. The learning outcomes were measured after the training followed by group interview.

Results: 202 students joined the study. The results revealed high levels of satisfaction and self-confidence in learning. Significant achievement in non-technical skills was perceived by the students. The level of satisfaction and self-confidence in learning, and the involvement and sensory fidelity domains in the sense of presence were positive predictors of NTS.

Conclusions: The promising results offer a basis for designing IVR activities for nursing education. Further investigations are imperative to determine its impact on learning outcomes in clinical practice.

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The promising results offer a basis for designing IVR activities for nursing education. Further investigations are imperative to determine its impact on learning outcomes in clinical practice.

Keywords: Nursing education; Simulation; Non-technical skills; Virtual Reality

Introduction

Immersive virtual reality (IVR) is a niche technology that has been rising in popularity in nursing education. In the past decade, clinical practice opportunities have declined for nursing students due to manpower shortages and an increasing demand for clinical services [1, 2]. Notably, virtual reality (VR) simulations were recognised for its tremendous potential in nursing education, which showed benefits in performance and knowledge in emergency skills training, and single patient management [3]. In some countries, simulation and other new technology-based training approaches have been accepted as alternatives to replace some of the required clinical hours [4]. Their potential to replace clinical hours became more evident from the closure of clinical venues during the COVID-19 crisis [2, 5]. To enable nursing students to develop the competence to solve problems in the clinical context, they not only need to apply the knowledge and skills that they have learnt, but to make decisions when facing situations that they were never taught or had never previously encountered. The question therefore is: Is VR-based education a plausible solution to strengthen clinical competence?

Virtual Reality in Nursing Education

VR is a rapidly expending field and its definition was complex ranging from the use of computer-based applications to generate simulated environments depicted on a computer screen to three dimensional environments with interactive functions and stimuli [6]. VR can be delivered as immersive or non-immersive modes to establish a varied perception of reality [7]. Examples of non-immersive modes include online or computer learning and video games. In contrast, IVR education tools or systems are usually delivered using a head-mounted device (HMD) to provide full immersion and interaction in a virtual environment. IVR 3D visualisation features make it possible to interact with the virtual environment and offer a deeper sense of presence that distinguishes IVR from web-based or two-dimensional technologies [8]. Bystrom, Barfield [9] defined a sense of presence as the subjective experience of participants being present within a virtual environment, which is a critical determinant of the level of engagement in immersive learning [10, 11]. Indeed, Dubovi, Levy [12] found that students' sense of presence within a VR training was positively associated with their conceptual and procedural learning of medication administration. In clinical simulation, a higher sense of presence also allows nursing students to assume a greater degree of responsibility for patient outcomes and reflect on their clinical reasoning and problem-solving skills [13]. We understand the benefits of repeatable training using a simulated environment for building self-confidence and self-efficacy in one’s performance without compromising safety for patients [14]. However, few studies have evaluated the relevance of a sense of presence in the acquisition of non-technical skills (NTS) in nursing students.

Non-technical skills

NTS are defined as cognitive and interpersonal skills that promote the safety and complement workers’ technical skills which included the domains of (1) Communication; Situation Awareness; Teamwork; Leadership; Decision Making [15]. Traditional health education has primarily focussed on the development of clinical knowledge and technical skills, often overlooking NTS [16]. However, increasing evidence links failures in NTS to poor patient outcomes [17]. In multidisciplinary settings, health professionals' leadership, teamwork, and communication skills are crucial for clinical competence and patient safety [18]. Additionally, in complex and dynamic environments, situation awareness—defined as an individual's perception, comprehension, and projection of events—and critical thinking, which involves reasoning, deducing, and inducing based on this understanding, are considered essential skills for healthcare professionals in making effective clinical decisions [19-22]. For instance, an examination of fatal medical accident reports submitted to a third-party safety agency in Japan over a three-year period found that approximately 50% of these incidents stemmed from failures in NTS, particularly those involving situational awareness, teamwork, and decision-making capabilities [23]. Thus far, most IVR have focussed on improving knowledge, mastering technical or procedural skills, developing emergency responses, or cultivating soft skills such as empathy and communication [24-26]. Only a very limited amount of VR software has been designed for learning NTS. Examples of these two aspects are task prioritisation according to professional guidelines [27] and managing a single patient and detecting deterioration [28, 29]. It is noteworthy that inconsistent results were found in high IVR on risk perception and safety training in high school students [30]. Systematic reviews revealed that VR was most effective in improving theoretical knowledge, but not affective outcomes and NTS [31-34]. More evidence is needed to substantiate the use of VR technology to prepare nursing students to meet clinical demands for the NTS.

Methods

Study design and objectives

This study adopted a multi-methods study design to investigate the efficacy of using IVR via the *VR-Hospital* (VR-Hosp) system (developed by the authors and their team) on developing NTS among undergraduate nursing students. The VR-Hosp (Short-term Patent: HK30083446) is a single-user game that was developed using Unity Pro and HTC Vive Cosmos. Its unique feature of adopting a multi-bed, multi-patient, multi-task approach aimed to create a realistic clinical environment with various situations that do not necessarily have a direct relationship to the patients' illnesses. From this, the following research objectives were derived:

1. To investigate the efficacy of the VR-Hosp on the students' (1) NTS (2) sense of presence in the virtual clinical environment, and (3) satisfaction and self-confidence in learning.
2. To identify the variables that predicted the NTS.

Qualitative data were collected through the focus groups to investigate the students' learning experiences.

Study participants and setting

The participants were undergraduate nursing students in a university in Hong Kong. They were recruited between year 2021-2022 through convenient sampling from a course "Fundamentals of Nursing", which was a mandatory subject for nursing students.

Virtual Reality-Hospital (VR-Hosp)

Conceptual Framework

A simulation model [35] was used to guide the development of the VR-Hosp. This model offered a framework to structure the objectives, fidelity, and complexity of the simulation design in relation to (1) the teacher-student factors, educational practices, (2) design characteristics and simulation, and (3) outcomes.

Teacher factors, student factors, and educational practices

The educational practices listed in the simulation model were active learning, feedback, interactions, expectations, diversity in learning, and time spent on tasks. In the VR-Hosp, unlike traditional teaching where learning experiences rely heavily on teachers, VR-Hosp is an immersive VR game with pre-determined instructions and game flow. As such, the practice factors are relatively standardised. The activities, time, and criteria for completion were preset based on the learning objectives. Therefore, the expectations were consistent even when the tasks differed. Students were required to make distinctions between and select their actions in response to various tasks to attain the designated goals. Active participation took place since the students had to play the game individually and proceed independently. They obtained prompt feedback on whether their actions were correct through answering multiple choice questions.

Design characteristics and simulation

According to the simulation model, design characteristics relate to objectives, fidelity, complexity, cues, and debriefing. The objective of using IVR in learning is to create a sense of presence that affects learning outcomes. This sense of presence is mapped on to the concept of learning space as delineated from the experiential learning theory [36]. The concept of learning space is that students learn through transactions between the person and the environment. This points to the need for fidelity and complexity in the virtual environment. Learners should be able to subjectively experience their needs, goals, unconscious influences, memories, beliefs, and events, when positioned in the dynamics, interdependence, tension, and forces of the environment.

The fidelity of the VR-Hosp was attained through validation of the content and the coherence of the stimulus and response elements between the VR and the actual tasks, according to four of the six principles stated in Harris, Bird [37]: (1) face validity – whether the VR game looks and feels realistic, (2) physical fidelity – details and realism of the physical elements, (3) psychological fidelity – perceptual and cognitive features of the real task, (4) affective fidelity – elicits emotional responses such as stress or fear in a similar way to the real task [38]. Construct validity that measures the distinction in performance between novices and experts was not examined at this stage. Ergonomic fidelity was deemed irrelevant since the VR-Hosp was not designed to train students in psychomotor skills.

Cues that popped up during the IVR game were essential to motivate and lead the students forward to complete the leaning tasks. In the VR-Hosp, such cues were available to guide them. Multiple-choice questions (MCQs) were also incorporated in the game. If a teacher-guided debriefing session was not available, when the students played the VR-Hosp individually or with peers the MCQs would allow them to reflect on their justification for the actions that they performed.

Intervention contents

In the VR-Hosp, an HMD and a controller held in the right hand were used for players to navigate inside the 3-D virtual ward environment, where there were three cubicles, with six beds in each cubicle. The VR-Hosp was evaluated by a panel of six experts, including three nursing academics with experience in developing VR games, and three clinical mentors with rich experience in supervising clinical placements. The game was pretested by another three clinical mentors and two nursing students for acceptability in terms of content, game instructions, and game flow before it was launched.

The VR-Hosp offered three scenarios. Each scenario lasted for approximately 10 minutes and was comprised of 2-3 levels of complexity tailored to students with different levels of clinical experience. The scenarios were named as follows: (1) clinical practicum orientation, (2) managing multiple tasks, and (3) prevention of errors. These three scenarios were developed to align with the learning objectives of the VR-Hosp: (1) being aware of safety issues, (2) being alerted to contextual incidents/ issues in the clinical environment, and (3) prioritising nursing activities. The three scenarios featured the unpredictability of the clinical context with unexpected issues arising randomly. Each scenario within the game provided a context that allows nursing students to apply and reinforce the learning objectives. By starting with simpler scenarios and progressively moving to more complex ones, the game aligned with the students' learning journey, ensuring an appropriate level of challenge and growth.

Each time a player logged in to the VR-Hosp, patient deployment, incidents, MCQs, and answer options were generated at random. The VR game used speech recognition and voice recording features (in Cantonese) for students to record dialogues in response to patients' needs or nurse instructions before implementing care.

The voice recording feature allowed players to respond to the requests of avatar patients or ward staff. This feature is unidirectional, i.e., players must carry out the required actions before progressing to the next step in the game, with the goal of challenging students to critically reflect on the course of actions without any external assistance. Once the players had completed the required action, the MCQs appeared to provide an opportunity for students to reflect on their responses and select the appropriate answers. The MCQs were developed based on the principle of reflective learning, facilitating a moment of re-evaluation and critical thinking, reinforcing the learning objectives and promoting a deeper understanding of the scenarios [39]. In addition, the voice recordings and answers can be reviewed after the VR-Hosp session. By revisiting their interactions, students can therefore identify areas for improvement, reinforce their learning, and engage in meaningful discussions during the debriefing.

Based on expert feedback, the response prompts were revised and optimized to provide clearer instructions and ensure a logical progression of clinical scenarios. Revisions to the MCQs were also guided by expert opinions to enhance clarity and alignment with learning objectives. For instance, to foster critical thinking and promote a comprehensive approach to patient care, the MCQs were refined to simulate realistic dialogues, moving away from standard textbook answers. Moreover, we added answer choices that encourage players to consider fall risk assessments instead of immediately helping the patient back to bed. The accuracy of the answers was verified, allowing for further refinements. To increase the realism of avatar patients and the clinical environment in the VR-Hosp, adjustments were made to the visual and behavioural aspects of the avatars to make them more lifelike and relatable, thereby facilitating realistic patient interactions. For example, in the VR-Hosp simulation, an elderly patient exhibiting an unsteady gait was depicted in the ward. His features were adjusted to more accurately reflect the movements typical of an older person. Additionally, to address the issue of VR sickness, we fine-tuned the visual and auditory elements, optimised frame rates, and implemented techniques such as smooth transitions and minimising sudden camera movements.
Figure 1 displays a cubicle (a), depicts the VR-Hosp environment with a ringing call bell during orientation (b), and shows a clinical pitfall with inconsistent signage on diet and the meal delivery trolley (c). These scenarios require students to be attentive to virtual environments found in clinical settings.

Procedure

Three sets of VR-Hosp equipment including HMDs and controllers, and 43-inch televisions mounted on movable stations were prepared for the students to practise on. There were a total of 19 groups of students, with 12-14 students per group. In the first 30 minutes of a 2-hour session, the students were given a briefing and practised operating the controller and the HMD in the VR environment. They were presented with one of three different clinical scenarios using the immersive VR-Hosp to deliver patient care in a hospital ward setting with three cubicles. Afterwards, they were divided into three teams of 4-5 students each, and played the VR-Hosp on their own. The members of each team took turns at being either a VR player or an observer, while the virtual game was played on the television screen at the same time to enable vicarious learning. The nurse tutor ensured each student in each group had the same amount of exposure to the VR-Hosp (i.e., 15 minutes), offered technical support on-site, and held a debriefing after each session.

Measures

The following outcomes were assessed immediately after the VR-Hosp session.

Virtual non-technical skills (v-NOTECHS)

The primary outcome measures five personal skills using a v-NOTECHS. Statements in the v-NOTECHS were modified from the original NOTECHS rating system (Sevdalis et al., 2008) to facilitate self-reporting on these behavioural parameters during the engagement to the VR-Hosp game. The v-NOTECHS consists of five domains: (1) Communication and Interaction (Communication) – 3 items, (2) Situation Awareness and Vigilance (Situation Awareness) – 3 items, (3) Cooperation and Team skills (Teamwork) – 5 items, (4) Leadership and Managerial skills (Leadership) – 5 items, and (5) Decision Making – 5 items. One item in the communication domain of the original scale 'waited for acknowledgement from scrub nurse' was deemed irrelevant in the VR-Hosp learning activities. Thus, it was deleted, leaving only three items instead of four in this subscale. The players rated on a 5-point Likert scale, where 1 = strongly disagree to 5 = strongly agree. Cronbach's α coefficients in the original scale ranged between 0.77 and 0.87. The reliabilities of the subscales administered to the target population are satisfactory, alpha values ranging from 0.70 to 0.90 (Communication = 0.70, Situation awareness = 0.70, Teamwork = 0.84, Leadership = 0.79, and Decision making = 0.90).

The Presence Questionnaire (PQ) Version 3.0

The Presence Questionnaire (PQ) was adopted to measure the players' sense of presence in this virtual clinical environment [40]. The scale explored how the players' psychological state or attention shifted from the physical to the virtual environment. It consists of four domains, a brief description of which is given as follows: (1) Involvement (Involve, 12 items) – How natural or compelling is it to interact with the environment and control the objects? (2) Adaptation / Immersion (Immersion, 22 items) – How much were you engaged in and focussed on the assigned tasks? (3) Sensory Fidelity (Sensory, 17 items) – the degree of coherence for stimulating multiple senses. (4) Interface Quality (Interface, 17 items) – How much did the control or display devices interfere with concentration on the tasks? The highest scores for these four domains were 84, 50, 42, and 21, respectively. Note that the items under Interface Quality were negatively worded. The item scores were reversed so that the higher scores indicated less distraction and delay in the game experience. The respondents gave their ratings using a 7-point Likert scale, ranging from 1 (strongly disagree) to 5 (strongly agree). The Cronbach's α coefficients of the four subscales were respectively 0.90, 0.85, 0.80, and 0.74.

Student Satisfaction and Self-Confidence in Learning (SSSCL)

The Student Satisfaction and Self-Confidence in Learning (SSSCL) scale was selected to investigate the design of the VR-Hosp practice[41]. The scale consists of five items for the satisfaction subscale (Satisfaction), measuring satisfaction with the content and instructions of the game. The second subscale, self-confidence in learning (Self-Confidence), has eight items, reported on a 5-point Likert scale. It measured the players' self-confidence in learning associated with the development of NTS. The internal consistency of the SSSCL was good. The coefficients were 0.92 and 0.82 for the satisfaction and confidence subscales, respectively. The instrument used in the present study also achieved an alpha of 0.93 for the satisfaction subscale and 0.91 for the confidence subscale.

Qualitative Data

An independent senior research assistant, who had been trained in conducting semi-structured interviews, led four online focus group sessions. Purposive sampling was used based on participants' socio-demographic background (i.e., gender, year of study) and whether they had exposure to clinical experience (yes, no) to ensure the representativeness of the focus group sample. Each group consisted of 4 to 5 participants. Another assistant was present to take notes. The main question posed to the participants was, 'Can you share your experience with the VR-Hosp game and how it affected your learning?' Further inquiries were made about the impact of the experience on their studies, the aspects they liked or disliked, and the skills, knowledge, and other benefits they acquired. Each group's digital audio recording lasted around 45 minutes and was transcribed word for word for further analysis.

Data analysis

Descriptive statistics were computed to show the demographic profile of the students and to capture their self-reported performance in developing their NTS using the VR-Hosp. Cronbach's alpha (α) was used to inspect the internal consistency of the questionnaires (criterion $\alpha \geq 0.70$: good reliability; $\alpha = 0.60$: acceptable) [42].

Hierarchical multiple linear regression was used to identify the incremental predictive values of different variables on NTS. In block 1, we aimed to establish baseline relationships by considering the influence of age and gender on NTS, as these socio-demographic characteristics can affect the development of NTS [43, 44]. In block 2, we accounted for experience-based factors, specifically prior clinical experience and VR game experience, which not only are associated with the development of NTS but also allowed us to establish their incremental predictive value on NTS beyond the influence of socio-demographic variables [45, 46]. Considering a sense of presence has been associated with more positive outcomes in technical skills among nursing students, in block 3, VR-Hosp game experience by PQ was included to determine its predictive value on NTS, taking into account the influences from the previous blocks [12]. Finally, the key predictors in the design of the VR-Hosp and confidence in mastering the teaching content using VR, as measured by the SSSCL subscale scores, were entered after taking into consideration the contributions in the previous blocks. The Technology Acceptance Model (TAM) consists of three key components—computer self-efficacy, perceived usefulness, and perceived ease of use—which were found to positively affect the behavioural intention to learn a health procedure [47]. We used the SSSCL subscale scores because the constructs measured by these subscales closely parallel the components of TAM. For example, the self-confidence subscale of the SSSCL is highly associated with the computer self-efficacy and perceived ease of use components of TAM, while the satisfaction subscale is closely linked to the perceived usefulness component [48, 49].

NVivo version 11 was used to manage the focus group data. Inductive content analysis was used to examine and analyse the interview data with the aim of identifying the main categories (themes) in the data, and patterns among the sub-categories [50]. The unit of analysis was a statement from the transcripts of the focus groups. The exploration and interpretation of the meanings of data led to the emergence of meaningful units of sub-categories, and a name was given to each sub-category corresponding to the meanings of its coding. Lastly, the sub-categories were condensed to achieve the status of a theme. To ensure trustworthiness, each transcript was analysed independently by two researchers (Chan, Lai), who then met to discuss the data and come to a consensus on the themes [50]. The researchers analysed the data until they reached the point of data saturation when no new findings emerged.

Ethical considerations

This study was approved by the Human Subject Ethics Sub-committee of the university. The students' participation was entirely voluntary, and would not affect their subject or curriculum in any sense.

Results

Participant characteristics

Of the 237 undergraduate nursing students taking the pre-clinical VR-Hosp workshop, 202 students consented and participated in the study. Among the participants, who had a mean age of 20.2 years (females: 150, 74.3%), 163 (80.7%) had no clinical experience, while the remaining students had less than 30 days of clinical experience, which included a subacute hospital placement (*n* = 40) and a medical-surgical ward placement (*n* = 9). It is noteworthy that more than 80% (*n* = 167) of the participants had no VR experience prior to the VR-Hosp. Sociodemographic characteristics are summarized in Table 1. The overall Cronbach's alpha coefficients of the three instruments were excellent (Table 2) at 0.93 (v-NOTECHS), 0.95 (SSSCL), and 0.92 (PQ), confirming that the construct was internally consistent (criterion α ≥ .070).

Efficacy on non-technical skills

The survey showed that the learning outcomes for NTS were largely satisfactory, with mean scores ranging from 4.1 to 4.3 out of 5 in the situation awareness and decision-making subscales. In the satisfaction with instructions and self-confidence in learning from SSSCL, mean scores of 4.3 and 4.2 were also reported respectively in the 5-point Likert scale. The sum of the scores for the four PQ domains were: involvement = 57.6, adaptation and immersion = 28.3, sensory fidelity = 39.6, and interface quality = 11.0 (Table 2).

Predictions on learning outcome

Self-confidence emerged as the significant predictor of three v-NOTECHS skills (Table 3), that included Situation Awareness ($\beta = -0.21$, $p = 0.032$, Adjusted $R^2 = 0.351$, $F_{2, 187} = 2.084$, $p \leq 0.001$), Team Skills ($\beta = -0.49$, $p < 0.001$, Adjusted $R^2 = 0.392$, $F_{2, 187} = 39.36$, $p \leq 0.001$), and leadership skills ($\beta = -0.31$, $p = 0.002$, Adjusted $R^2 = 0.377$, $F_{2, 187} = 22.32$, $p \leq 0.001$). Satisfaction was documented as the significant predictor of two v-NOTECHS skills. They are communication and interaction ($\beta = 0.34$, $p = 0.001$, Adjusted $R^2 = 0.336$, $F_{2, 187} = 20.01$, $p \leq 0.001$), and decision making ($\beta = 0.39$, $p < 0.001$, Adjusted $R^2 = 0.392$, $F_{2, 187} = 33.44$, $p \leq 0.001$).

Qualitative data

Basic patterns and coding were clustered and organized into categories (Table 4). The content analysis yielded three categories corresponding to user experience and intended learning outcomes (ILOs). The first category pointed to the fidelity of the VR-Hosp. The sub-categories were physical fidelity, psychological fidelity, and affective fidelity. The other two deduced categories were found to match with the items in the SSCL subscales and v-NOTECHS, and thus were named satisfaction in learning and development of NTS. The items in the satisfaction subscale indicated the effectiveness of the VR activities in promoting enjoyment and motivation to learn. Items in the self-confidence in learning subscales point to the development of the expected knowledge and skills as specified in the v-NOTECHS instrument measuring self-reported learning outcomes.

Category I: Fidelity

Realism was noted in the VR-Hosp.

Physical fidelity

Not only was it observed that ‘the graphics and images were constructed in detail’ (0207), but the narrow working space between beds was also simulated (0304), and ‘a patient suddenly climbed out of bed and ran really quickly’ (0310). The chaotic situation in clinical settings was further revealed when discrepancies were noted when the food in the meal cart differed from that indicated in the signage above the patient’s bed (1405).

The positive reports from students that VR-Hosp provides a realistic simulation consistent with a hospital environment are corroborated by the quantitative findings of high sensory fidelity scores in the PQ, which measures the degree of coherence in stimulating multiple senses.

Psychological fidelity

The students continually tried to make sense of the chaotic and ad hoc incidents occurring in the virtual environment. Nurse 0307 mentioned,

‘I actually experienced the chaos of clinical practice. It feels like what I have learnt was not actually “learnt”’.

Another student was stunned by having to do a voice recording in response to the assignment on the patients’ needs and the nurse’s tasks. The importance of communication became clear, moving the focus solely on psychomotor skills to understand the patients’ needs (0608).

The unexpectedly immersive learning experience was closely aligned with the level of involvement—specifically, how natural or compelling it is to interact with the environment and control objects. This was particularly evident when students had to create a voice recording in response to an assignment on patients' needs and nurses' tasks, prompting them to reflect on the importance of communication in addressing patients' needs.

Affective fidelity

Tension was reported in the realistic situations embodied in the immersive interactions in the VR-Hosp. ‘In the virtual game, I heard an alarm go off. This would not have occurred in laboratory practice. This made me feel very nervous’ (0204), and ‘I felt overwhelmed’ (0811).

These qualitative findings were also corroborated by the adaptation and immersion scores, which assessed how engaged and focussed participants were on the assigned tasks. Tensions observed from the realistic and immersive interactions in the VR-Hosp offered them a novel learning experience beyond traditional laboratory practice.

Category II: Satisfaction in learning

In this category students said that this training method was helpful and effective.

‘Traditional teaching was somehow fragmented, and only focussed on a specific area . . . This VR-Hosp offered us a chance to understand the workflow. In this way, we have learned better’ (0706).

Not only did they come across various situations that they ‘did not see in textbooks’ (1303), but they had to ‘analyse information before reporting the patient’s condition’ (1109). Students enjoyed the learning activities *and asserted that the games* motivated them to learn. Nurse 1503 said,

The game that I played was distributing meals to the patients. I didn’t realise that the meal signage could differ from the actual order.

Category III: Self-confidence in learning

Development of communication and interaction

Communication and interaction skills are core components of NTS. Multiple students highlighted how the VR experience helped them realise the importance of these NTS, which they had previously overlooked (0608, 0908 1306). Another student also added,

'I know communication is important, because I have to respond and find out the priorities of various situation' (0913).

Development of situation awareness

Situation awareness was perceived as a vital skill by many students. Now, they had learned to be observant and alert not only to the environment, but also to the patients' actions to ensure patient safety. As one student mentioned, 'Being a nurse, we have to be highly alert since so many different things could happen . . . What if I did not pay attention and the patient suddenly collapsed?' (0410). Another student echoed,
'Many a time during laboratory practice, we perform the skills in a step-by-step manner. But in reality, it would not happen as planned. There would be sudden incidents' (1312).

Development of decision making

Decision making was one of the central learning outcomes. Knowledge and clinical reasoning all came to play. Moreover, prioritization was deemed to be essential since tasks came up one after another (0710). '[We] have to judge by ourselves' (0105, 0211, 0510, 0907) was a comment that was made many times. 'we needed to determine the priority' (1301). We learned to 'analyse the information' (1008, 1506), think critically (1401), and know the rationale for our actions (0311).
Nurse 1004 pointed out that 'It felt so real that you would be asked to do another thing while you are busy'. The students found that they will need to 'multitask' (1403), and that 'there is an internal timer' (0713). One student best summarized the experience of playing VR-Hosp as, 'We had to be efficient, accurate, and careful' (0406).

Discussion

This study was the first of its kind to explore nursing students' experience in using immersive VR-Hosp in learning NTS. All in all, these findings suggested that the VR-Hosp had the potential to facilitate learning NTS to complement current educational strategies.
Both quantitative and qualitative findings indicated the positive effects of VR-Hosp training in enhancing nursing students' NTS through a high-stress, time-critical IVR environment that customised real-life clinical situations with multitasking and episodes of interruption, demanding heightened awareness and prompt decision-making. Sensory fidelity signified the realism and coherence of the senses, for example sound and movement, and the examination of virtual objects from multiple viewpoints. Huang, Luo [51] found that a high sense of presence might have generated a cognitive overload when individuals were trying to complete the virtual tasks, and thereby negatively affected satisfaction [52]. In contrast, visual, auditory, and tactile stimulation were found to be vital for novice nurses to detect cues related to the patients' conditions [53, 54]. In a similar vein, sensory fidelity in VR-Hosp allowed the students to play individually with high concentration and meticulous cognitive and perceptual responses, to critically think and make appropriate decisions. Consistent with another study, sensory modalities to imitate real-world movements were crucial in learning [55].
In our quantitative findings, critical sensory input was found to be associated with perception and comprehension of the situation [56]. More importantly, the meaningfulness and coherence of the content and activities have been established as factors that promote learning and the goals of higher

education [57]. The high satisfaction and self-confidence scores coupled with their predictions of these two NTS unpacked the meaningfulness of using VR-Hosp. These findings were further complimented by students' feedback, which indicated that the present virtual environment realistically offered space for the students to make decisions and react to the visual or auditory alarms instead of providing a step-by-step guide. The students were required to multitask within a set period and to tend to episodes of sudden demands. Prioritization and communication with the patient or other members of the healthcare team was significant. Students had to contemplate the rationale for their actions and reconsider their justifications when answering the MCQs in response to the virtual situations. Hence, the IVR activities facilitated the building of situation awareness and vigilance, and decision making.

The qualitative findings provided further insights on the distinct contributions of its design to the development of NTS among nursing students. Detecting and handling alarms, hazards, and clinical pitfalls were the learning activities in VR-Hosp. Students commented how VR-Hosp heightened their excitement, eliciting stress and nervousness when encountering unexpected incidents and equipment alarms during the game play. It was uncovered that the voice recording feature in the VR-Hosp made the students feel compelled to communicate with the nurse and patient during the game. They could not proceed to the next action if they did not talk to the patients and other healthcare workers. Such forced interactions urged them on to communicate with the avatar and engaged them to perform the designated activities. Altogether, these qualitative findings echoed the learning space concept in experiential learning framework [36], contributing evidence of VR-Hosp's sensory fidelity value to physical, psychological, and affective fidelity.

Previous studies reported that gender and experience in playing VR games were factors that affected the satisfaction and usability scores [24]. In contrast, our quantitative findings revealed that gender and literacy in VR technology did not have an impact on situation awareness and decision making. It was interesting to discover that the other three domains in the sense of presence did not predict either situation awareness or decision making. These domains were involvement – controlling and moving in the virtual environment, Immersion – proficiency and consistency with the real world, and interface quality. This means that interference in using the control devices, delay in experiencing actions, and distraction in visual display did not hinder the students' confidence in their ability to develop the desired skills. It was inconclusive whether naturalistic interactions was the element that influenced how the form and content of the learning modalities operate in virtual learning environments [58]. That said, it was likely that exposure to IVR clinical practice was significant in helping novice nurses to develop and master the skills of situation awareness and decision making regardless of the control of the VR devices.

Taken together, the present study offers evidence on the sensation fidelity of the VR environment as an essential feature to achieve learning outcomes. Our findings suggest that the VR-Hosp had the potential to facilitate the development of situation awareness and decision making, complementing current educational strategies. For instance, the IVR provides a cost-effective and accessible alternative to the traditional pedagogy, such as high-fidelity simulation. While high-fidelity simulation is an effective educational strategy, certain limitations such as manpower, resources, space, and the availability of qualified facilitators can impact its implementation and effectiveness. On the other hand, IVR eliminates the need for physical resources and dedicated space, allowing students to engage in realistic scenarios using VR headsets or other devices. This scalability enables a larger number of students to participate simultaneously, enhancing accessibility and reducing logistical constraints. With the use of IVR, facilitators can guide and debrief students, leveraging the recorded interactions and performance data to provide targeted feedback and facilitate reflective learning.

Limitations

The present study adopted a convenience sampling method; thus, it is difficult to generalise the results. It involved a cross-sectional survey collected after the VR-Hosp practice; thus, the cause and effect of this VR teaching strategy could not be determined. NTS in the real world are often influenced by external factors such as high uncertainty and time pressure [59]. Considering that the v-NOTECHS scores were self-reported, further work is needed to objectively evaluate the learning outcomes and assess whether these skills can be sustainably translated to realistic settings. When implementing the VR-Hosp, students took turns in being players and observers. This might have interfered with the immersive experience since the observers communicated with the players during the activity, for example, in locating the alarms and when answering the MCQs. There might also have been bias when obtaining the qualitative feedback, since the process was conducted during the debriefing session moderated by the teachers. However, the information that was obtained forms a basis for future studies to compare its impact with that of other educational pedagogies. In addition, the use of HMDs in IVR can lead to VR sickness, such as nausea, dizziness, and blurred vision [60]. While our study did not report cases of VR sickness, its presence could negatively impact the immersive learning experience. Future research should include measures like the Virtual Reality Sickness Questionnaire to evaluate its effect on the desired learning outcomes [61]. Additionally, future studies using IVR may consider striking a balance between realism and incorporating elements shown to reduce VR sickness, such as narrowing the horizontal field of view, partially limiting degrees of freedom in navigation control, and increasing tactile feedback [62].

Conclusions

The VR-Hosp appears to be a promising educational pedagogy for enhancing NTS including the situation awareness and decision-making abilities in nursing students. VR-Hosp portrayed a non-linear world that challenged the students to operationalise what they had learnd in traditional classroom teaching and simulation practices. The findings add evidence to the determinants of learning outcomes from the aspects of a sense of presence, satisfaction, and self-confidence in learning. It should motivate the undertaking of future work on VR-based teaching and learning activities in higher education.

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Author contributions

All authors have substantial contributions in: (1) developing the IVR game ‘Virtual Hospital’ software, (2) developing the conception and design of the study, (3) acquiring data, or analysing and interpreting the data, and (4) drafting the article or revising it critically for important intellectual content have agreed on the final version of the manuscript.

Conflict of Interests

The authors declare that they have no conflicts of interest concerning the development of the Virtual

Hospital or the research.

Informed consent

Informed consent was obtained from all individuals included in this study.

Ethical approval

Ethical Approval was obtained in the Hong Kong Polytechnic University (number: HSEARS20211229002).

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Tables

Table legend
Table 1. Demographic and outcome measures after the Virtual Hospital game
Table 2. Hierarchical regressions analysis
Table 3. Content analysis: Overview of categories and sub-categories

Table 1. Demographic and outcome measures after the Virtual Hospital game and reliabilities of the scales.

Demographic Data	(*N* = 202)	
	N	%
Age (mean ± *SD*)	20.2 (± 1.45)	
Gender		
Male	52	(25.7)
Female	150	(74.3)
Clinical Practicum Experience		
No clinical experience yet	163	(80.7)
Clinical placement for 15 days	27	(13.4)
Clinical placement for 30 days	12	(5.9)

Experience in playing immersive virtual reality game		
Never	166	(82.2)
1-3 years	36	(17.8)

Outcome Assessment	Mean	*SD*	Cronbach's Alpha
Virtual non-technical skills (v-NOTECHS)			0.934
Communication and Interaction^	4.3	0.54	0.699
Situation Awareness and Vigilance^	4.1	0.55	0.699
Cooperation and Team Skills^	4.1	0.55	0.840
Leadership and Managerial Skills^	4.1	0.50	0.788
Decision Making^	4.1	0.52	0.900
Student Satisfaction and Self-Confidence in Learning (SCLS scale)			0.948
Satisfaction with the content and instructions^	4.3	0.56	0.929
Self-confidence in Learning^	4.2	0.53	0.909
Presence Questionnaire (PQ)			0.924
Involvement (max. score: 84)	57.6	8.71	0.900
Adaptation and Immersion (max. score: 50)	28.3	4.95	0.851
Sensory Fidelity (max. score: 42)	39.6	5.95	0.795
Interface Quality (max. score: 21)	11.0	3.39	0.740

^ Max. score=5

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Table 2. Hierarchical regressions analysis

Block of variables	*Communication and Interaction*			*Situation Awareness and Vigilance*			*Cooperation and Team skills*			*Leadership and Managerial skills*			*Decision Making*		
Predictors	*ß*	*p*	$\triangle R^2$	*ß*	*p*	$\triangle R^2$	*ß*	*p*	$\triangle R^2$	*ß*	*p*	$\triangle R^2$	*ß*	*p*	$\triangle R^2$
BLOCK 1															
Gender	0.03	0.649	0.006	0.040	0.535	0.004	0.090	0.202	0.010	0.140	0.056	0.019	0.089	0.213	0.008
Age	0.07	0.314		-0.050	0.522		-0.040	0.622		0.010	0.926		0.011	0.883	
BLOCK 2															
Gender	0.04	0.611	0.002	0.060	0.423	0.017	0.100	0.152	0.016	0.140	0.060	0.001	0.093	0.198	0.004
Age	0.07	0.394		-0.030	0.757		-0.040	0.164		-0.010	0.880		-0.007	0.929	
VR Experience	0.05	0.520		0.120	0.112		0.130	0.076		0.010	0.868		0.058	0.423	
Clinical Experience	-0.01	0.908		-0.080	0.310		-0.030	0.716		0.040	0.648		0.020	0.808	
BLOCK 3															
Gender	-0.01	0.881	0.186***	0.010	0.886	0.226***	0.070	0.341	0.110***	0.080	0.204	0.208***	0.040	0.507	0.163***
Age	0.11	0.152		0.010	0.924		-0.020	0.813		0.020	0.769		0.010	0.888	
VR Experience	0.03	0.666		0.100	0.131		0.120	0.092		-0.010	0.858		0.040	0.556	
Clinical Experience	-0.02	0.778		-0.080	0.290		-0.030	0.659		0.030	0.694		0.020	0.763	
Involvement	0.30	0.024		0.250	0.046		0.120	0.363		0.180	0.153		0.000	0.976	
Sensory	0.16	0.134		0.270	0.007		0.210	0.055		0.110	0.258		0.220	0.036	

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Fidelity															
Immersion	0.00	0.990		-0.010	0.900		0.030	0.810		0.190	0.065		0.230	0.033	
Interface Quality	-0.12	0.078		-0.030	0.616		-0.090	0.202		-0.130	0.044		-0.090	0.188	
BLOCK 4															
Gender	0.03	0.594	0.142***	0.030	0.574	0.104***	0.090	0.135	0.256***	0.110	0.073	0.149***	0.090	0.109	0.217***
Age	0.09	0.196		0.000	0.981		-0.020	0.741		0.010	0.827		-0.010	0.871	
VR Experience	0.04	0.563		0.100	0.082		0.130	0.026		0.000	0.972		0.050	0.407	
Clinical Experience	-0.04	0.539		-0.090	0.163		-0.060	0.350		0.010	0.908		0.000	0.961	
Involvement	0.24	0.041		0.210	0.072		0.070	0.540		0.140	0.231		-0.070	0.560	
Sensory Fidelity	0.14	0.130		0.270	0.005		0.210	0.021		0.110	0.215		0.210	0.022	
Immersion	-0.14	0.170		-0.130	0.190		-0.150	0.122		0.060	0.561		0.060	0.514	
Interface Quality	-0.05	0.441		0.020	0.776		-0.030	0.654		-0.080	0.200		0.000	0.940	
Self-confidence	0.10	0.325		0.210	0.032		0.490	< 0.001		0.310	0.002		0.160	0.103	
Satisfaction	0.34	0.001		0.160	0.118		0.080	0.414		0.140	0.174		0.390	< 0.001	
Adjusted R^2	0.336***			0.351***			0.392***			0.377***			0.392***		
F Change (p)	$F_{2,187}$	20.01		$F_{2,187}$	15.03		$F_{2,187}$	39.36		$F_{2,187}$	22.32		$F_{2,187}$	33.44	

**p* £ 0.05. ** *p* £ 0.01. ****p* £ 0.001.

ß = standardised coefficient Beta.	

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Table 3. Content analysis: Overview of categories and sub-categories.

	Categories		Sub-Categories	Selected Sample Quotes	Nurse number
1.	Fidelity	i.	Physical fidelity – detail and realism of the physical elements	The experience is fun. The graphics and images were constructed in details.	0207
				Learn in a realistic situation. Before playing the VR game today, I did not realise that one nurse has to take care of so many patients. I cannot believe there are so many beds, and the space between beds are so narrow, which barely allow one medicine cart to get through.	0304
				There are a lot of situations. When we play the game, each one of us will face a different situation. In my case, a patient suddenly climbed out of bed and ran really quick, and said he wanted to make a phone call. I chase after him. I felt such things could have happened in real settings. So it is a very special experience.	0310
				It is easier to control the VR device than what I thought. For example, it is easy to control the meal cart and the dressing trolley. Other students measure blood pressure when they played, but I distributed meals in my turn. I have never thought of what I would have experienced! I should have checked the overhead signage and double confirm the meal before I offer it to the patient.	1405
		ii.	Psychological fidelity – replication of the perceptual-cognitive demands of the real task	I actually experienced clinical practice and was in chaos. It feels like what I have learnt was not actually 'learnt', and I seemed to know nothing and do not know what to do. I needed to handle so many things, and I felt I am now psychologically prepared for later clinical practicum. It is so important that I have to revise my books.	0307
		Iii	Affective fidelity – elicit emotional responses such as stress or fear in a similar way to the real	In the virtual game, I heard alarm went off. This would not have occurred in laboratory practice. This made me feel very nervous	0204

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			task		
				I had to work independently in the entire ward, and I felt overwhelmed	0811
2.	Development of non-technical skills	i.	Communication and Interaction	It was really fun to play the VR game. Perhaps I only focussed on the skills in my usual practice. I now realised that I have to communicate to the patients to let them understand what is going on.	0608
				I think it is really good that we have to voice record, and communicate with the nurse or the patient. We seldom have anyone talking to you when you practice.	0908
				I know communication is important, because I have to respond and find out the priorities of various situation'	0913
				In the past, we only learn about the skills. In this VR game, we practice in realistic scenarios. We have to talk to the nurse in charge. In general, that is something you were not taught in the class.	1306
		ii.	Situation Awareness	Being a nurse, we have to be highly alert since so many different things would happen. . . What if I did not pay attention and the patient suddenly collapsed?	0410
				We need to be careful. I need to respond immediately when a patient choked. Many a time during laboratory practice, we perform the skills in a step-by-step manner. But in reality, it would not happen as planned. There would be sudden incidents	1312
		iii.	Decision Making	It is fun. I just measured the blood glucose. I have to analyse the information. After I had made the wrong conclusion twice, I picked up how I could act appropriately according to the different blood glucose values.	1506
				When I went to the nursing station and talked to the nurse, she asked me to perform a task. However, we do not just follow what was told, but we have to judge by ourselves. It is close to the realistic situation. It is fun.	0211
				After playing the VR, I realised that a nurse have to handle	0510

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	numerous tasks. While you were taking blood pressure, suddenly you were asked to perform a wound dressing. We have to justify and prioritise instead of following the routine.	
	I played scenario 3, and administered the wrong medication. Often times, I realised that there would not be someone guiding you all the time. If your knowledge is deficient, you cannot help others. As such we made mistakes. Now I realised, to be a nurse, we have to do better. Therefore, I have to be knowledgeable.	0407
	I learnt how to communicate with other colleagues. Apart from finishing my job at hand, I have to take up newly assigned tasks. A nurse at the nurse station would suddenly asked you to perform wound dressing when you are taking blood pressure. Multitasking was needed, and you have to prioritise the tasks.	1403
	It felt so real. You have to finish some task with a set time. It reflected that we have to be practice more so as to be more proficient. Prioritisation were deemed essential since work comes one after another.	0710
	I just finished scenario one. I could not say the tasks were very difficult. However, we had to be efficient, accurate and careful. Hence, when an alarm went off, you have to walk around and observe for what happened. You have to be aware even a bed was not locked, otherwise that patient would be endangered.	0406
	I felt that the VR game is so different from traditional classes. There would not be a load of task to perform. However, today, I went to the VR ward, there are heaps of tasks. You will have to memorise what to prepare and do aftercare. Moreover, although no one really time it for you during your work, but there is always an internal timer.	0713
	It felt realistic. A senior nurse would ask to do another thing while you are busy. You have to explain to them the situation.	1004
	We had to familiarise with the situation. In general, there were numerous tasks for you to perform. We have to judge and	0907

				prioritise according to our rationale. The workflow should be more smooth.	
				Like realistic situation, it is not a must to perform a specific task in a set sequence. We can have our own judgement.	0105
				When sudden issues arose. For instance, while you were performing a wound dressing, sudden a call bell rang. We needed to determine the priority how you proceed to manage these situations.	1301
				I felt very good. I did not have any clinical practice experience. This is a good chance to learn. We need to complete a lot of tasks in 10 minutes. I have to plan and priorities the tasks. I trained my critical thinking.	1401
				I have to check the record prior to blood sugar measurement, and analyse the information. This helped decision making in the next step.	1008
				The activity is interesting to me. I have to change bed sheets and perform wound dressing. This is when I need to understand the priorities between these two tasks. At first, I thought it doesn't matter. However, there is a reason why you made a certain choice. Next time when I practice in the ward and were asked to perform another task in the middle of my work, I knew the rationale of our actions. How to respond was also another skills to learn.	0311
2.	Satisfaction in Learning	i.	Training method is helpful and effective	Traditional teaching was somehow fragmented, and only focussed on a specific area . . . This VR-Hosp offered us a chance to understand the workflow. In this way, we have learned better'	0706
				I encountered various situations that was not seen in textbooks. For example, I was asked to take care of a patient who was vomiting.	1303
				I could try many tasks, wound dressing, etc. After analysing the information, then I have to report the patient's condition.	1109
		ii.	Enjoyed the activities	It was fun! I realised that we have to do the right assessment and care to the right patient.	1503

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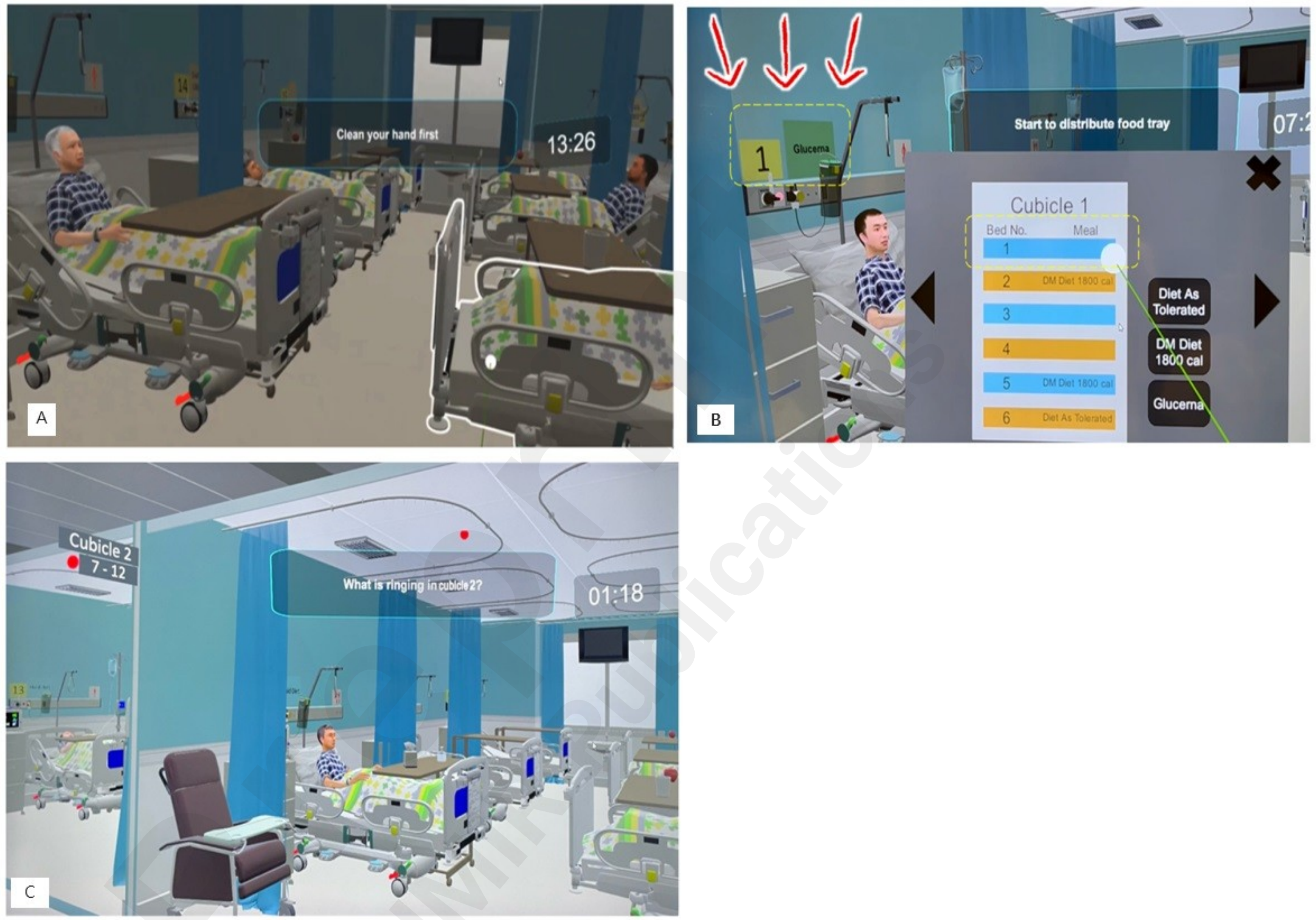
Figures

Figure. 1. Screen capture of the VR-Hospital



Supplementary Files

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Figures

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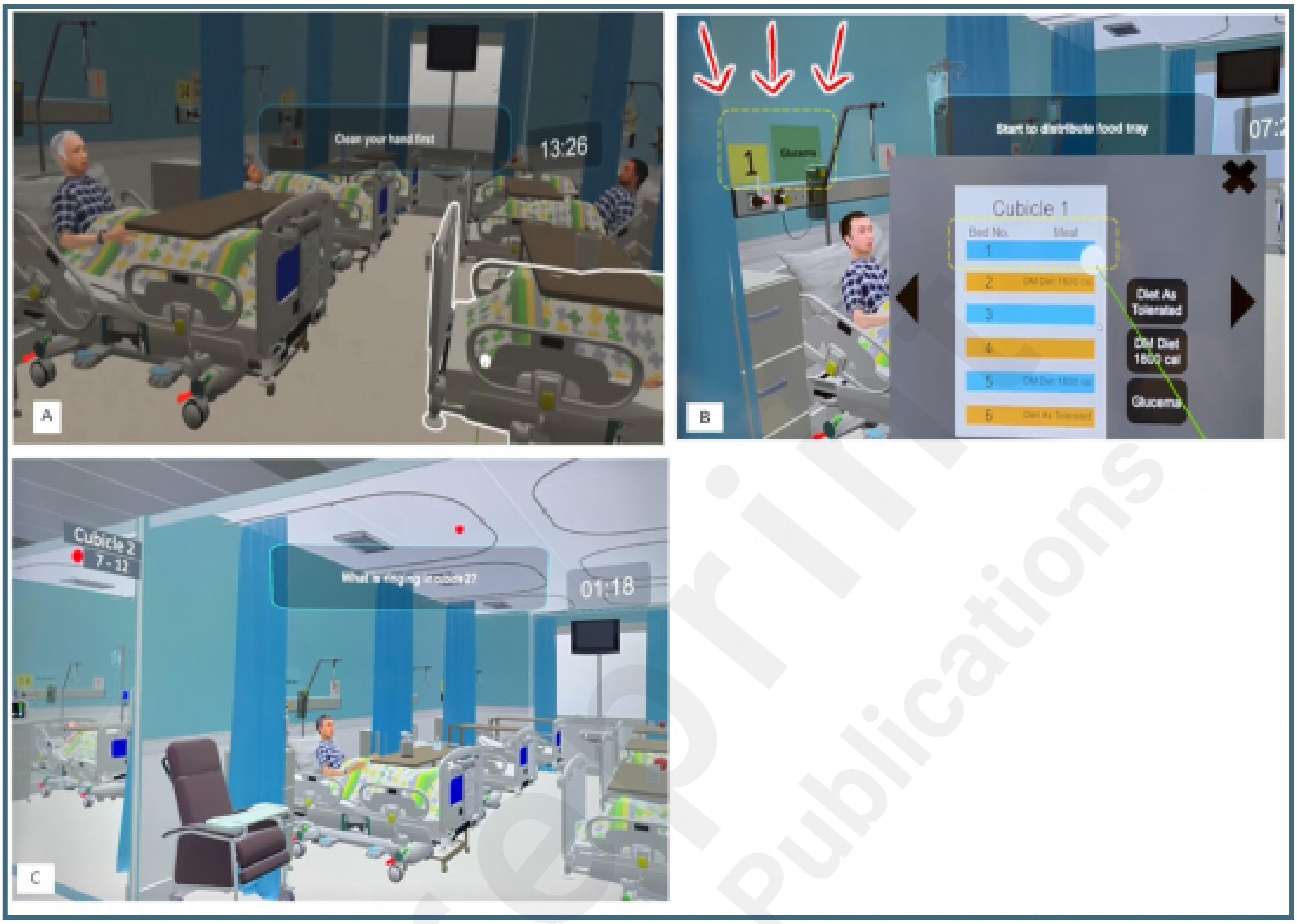
Screen capture of the VR-Hospital.



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