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Research Article

Effect of Non-Immersive Virtual Reality Simulation on Type 2 Diabetes Education for Nursing Students: A Randomised Controlled Trial

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KEYWORDS
Technologies;
Virtual reality;
Nurse education;
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PLS-SEM;
Type 2 diabetes

Abstract
Background: A virtual reality simulation was used to teach treatment of diabetic patients.
Methods: This study evaluated the impact of using virtual reality on short term knowledge of hypoglycaemia, via pairing of a randomised controlled trial, analysed via Partial Least Squares-Structural Equation Modelling. The setting was two large lecture theatres based at campuses within the UK. Second year nursing students (n = 171) volunteered to take part in the study. Students were randomised into two groups, control (n = 88) and experimental (n = 83). The trial enabled comparison, via pre and posttest surveys, of the simulation with normative teaching methods.
Results: VR was found to be significantly ($p \leq .001$) better in terms of hypoglycaemia knowledge thannormative methods. The method also enabled identification of the key point of action of the simulation, which evidenced that the "engagement to immersion" pathway was responsible for leading to higher knowledge scores in the experimental group.
Conclusion: This paper claims addition to knowledge about how the novel approach taken has the potential to deepen understanding of how virtual technologies can affect learning in nurse education.

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Introduction

Worldwide one in 11 adults (2-79 years) have diabetes (463 million people) of which 90% have type two diabetes (International Diabetes Federation, 2019). Diabetes and its treatment are complex, and studies have indicated that the level of general diabetes knowledge amongst registered nurses is deficient (Alotaibi, Al-Ganmi, Gholizadeh, & Perry, 2016; Chan & Zang, 2007; Vincent et al., 2016; Yacoub et al., 2014). Hypoglycaemia, when the blood glucose drops below 3.9 mmol/L or 72 mg/dl, is considered a diabetic emergency and it is essential that nurses are able to support and manage patients in this situation (American Diabetes Association, 2020). Both patients with Type 1 and Type 2 diabetes can experience hypoglycaemia which is the most common side effect of insulin or sulfonylurea therapy. It occurs due to an imbalance between the available glucose and insulin levels (Walden, Stanisstreet, & Graveling, 2018). One in five patients with diabetes are likely to experience a hypoglycaemic event in hospital and it is vital that all nurses are equipped to identify and manage this situation (Ndebu & Jones, 2018). Some student nurses find it challenging to learn about the management of hypoglycaemia (Chan & Zang, 2007) and this paper examines the use of VR simulation as a method to improve their knowledge and understanding.

Key Points

- Instant feedback embedded in the VR simulation, was deemed to be a clear advantage in accelerating learning when diagnosing and treating a deteriorating patient.
- The VR simulation provided opportunities for safe practice of clinical skills at a place and time of the learners choosing.
- VR simulation can be an inclusive and engaging learning approach that does not depend upon prior VR user experience.

Simulations are increasingly being offered as part of the educational experience in health care subjects and are being progressively valued for their more authentic approaches in preparing for live clinical experience (Bayram & Caliskan, 2019). This paper reports on a research project to test the potential uses of Virtual Reality-based simulation in improving nurse education in relation to managing diabetes, especially in relation to recognising deterioration in patients due to hypoglycaemia.

Definition of Virtual Reality Used in This Paper

Virtual Reality (VR) is a widely used term that can refer to a range of online environments with which users can interact. In general, the characteristics of VR include (Radford, Connaway, Confer, Sabolcsi-Boros, & Kwon, 2011):

- the creation of a detailed 3D computer-generated environment.
- The environment supports multiple users (multiple avatars can be present at the same time).
- User interaction is through the agency of avatars.
- Avatars can move around the 3D space and interact with some items in that space.
- There are interactive communication systems such as text chat and voice.

In VR, users experience an independent, simulated environment, rather than experiencing an overlay of virtual space onto the physical world as in Augmented Reality (AR). In this paper, we describe and evaluate a 3D VR simulation which has all of the characteristics listed above. Participants experienced the environment through a laptop screen and controlled their actions through use of the keyboard.

Theoretical Framework

There is a paucity of quality published literature on the application and/or integration of VR into nursing education (Fealy et al., 2019). Much of the education and training research focuses on high risk, invasive skills such as endoscopy and surgery (Rourke, 2020). Furthermore, research into health care education shows inconsistent evidence regarding VR simulation use, partly due to unclear definitions of what is meant by VR, and different approaches to its use. For example, Cook, Brydges, Zendejas, Hamstra, and Hatala (2013) indicated that non-immersive VR simulation contributes insignificant differences in knowledge outcomes in comparison to normative instruction, whereas Sweigart and Hodson-Carlton (2013) found significant improvement among student nurses using a psychiatric assessment tool when using virtual worlds. A meta-analysis carried out by Consorti, Mancuso, Nocioni, and Piccolo (2012) showed a clear positive net overall effect of learning gains with VR simulations, but Kunst, Henderson, and Johnston (2018) found that inconsistency in the methods used to evaluate VR simulation activities creates challenges in providing definitive answers about the benefits. Therefore, researchers (e.g., Hirt & Beer, 2020; Wan & Lam, 2019) are calling for more rigorously conducted studies with robust designs to generate knowledge of what might be an effective learning strategy in nurse education. For this reason, we took a novel and robust approach to the design of our research, both in relation to carrying out the study and analysing the results, which is described and discussed in section 3 below.

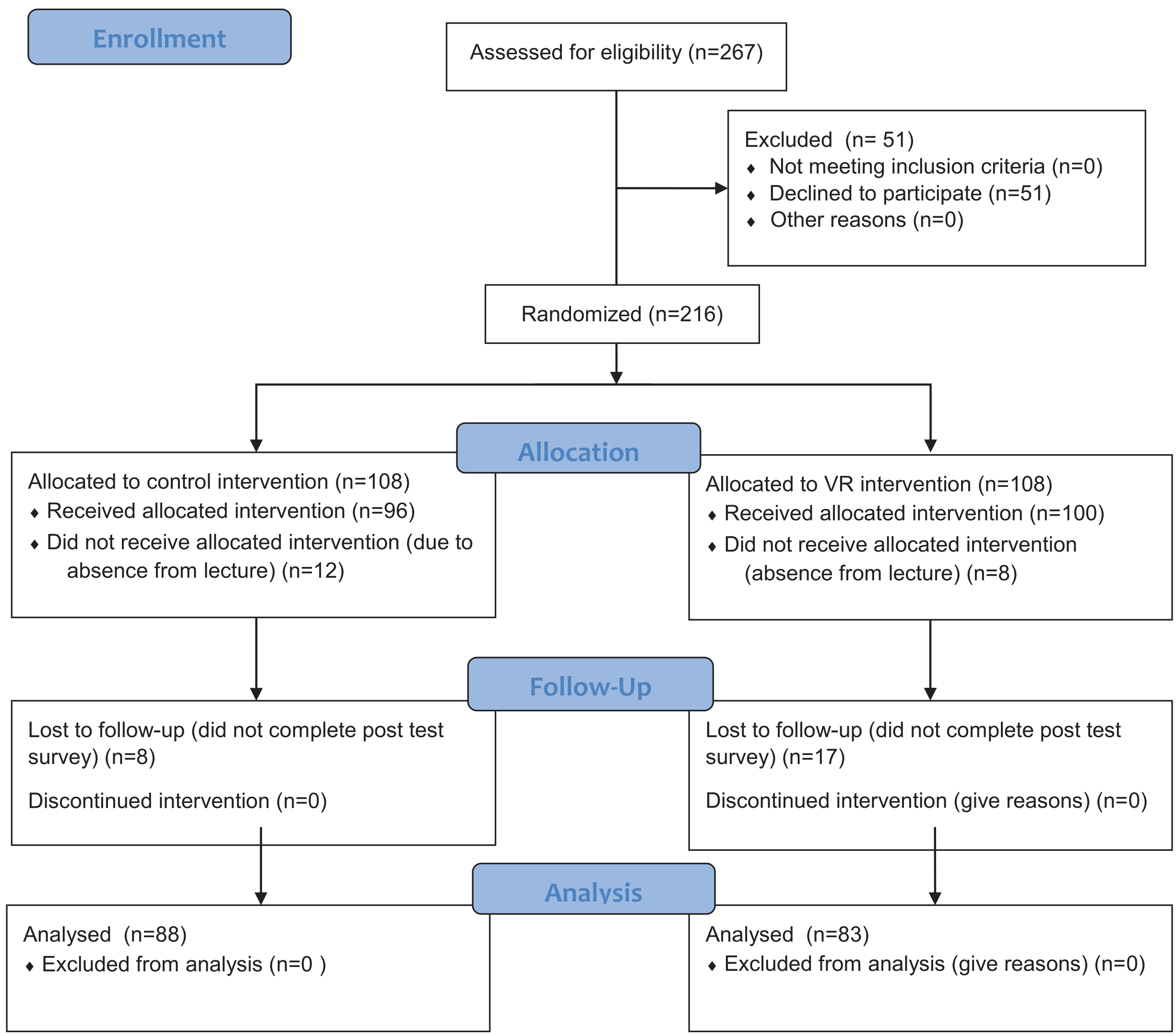

Figure 1 Consort 2010 flow diagram.

Materials and Methods

Basis for the Research Design

We designed the research protocol based upon a conceptual framework drawn from the findings of a Critical Realist (CR) literature review. CR is a branch of philosophy that distinguishes between what is 'real' and what is 'observable'. Taking account of the issues of inconsistency in methods to evaluate the effectiveness of VR discussed above, a CR approach was most appropriate to identify what has been observed in VR education research, whilst recognising that there will also be unobservable variables that are likely to contribute to what is being observed. The inclusion criterion for articles in the first round of the review were that they needed to address VR for a Higher Education (HE) population, including populations from anywhere in the world. For subsequent refining of identified articles, they needed to address developing theoretical assumptions from an observational viewpoint, that is, what theoretical assumptions regarding influences on student learning are being developed from what is being observed in research findings?

The main question of the CR literature review was: "What factors are being observed to influence student learning when using virtual reality?" Database sources of literature were ERIC, Education Source and CINAHL, from their first available date until April of 2019 using "virtual reality," "Higher Education," and "learning outcomes" as broad search terms. After the initial search, 81 articles were retrieved. Articles were retained if they met the inclusion criteria for each phase of the refining process, which resulted in 36 articles contributing to the review. Thematic analysis of those papers resulted in five factors having been observed to influence student learning, namely experience, immersion, engagement, confidence, and knowledge.

Figure 2 The VR simulation exercise.

The Research Hypotheses

The research was carried out with two groups of second year adult and mental health nursing students at a University in the South of England. One group experienced the VR simulation (the experimental group) and one group experienced traditional teaching techniques (the control group). Our base hypothesis was that students randomly selected to learn about complex diabetes concepts using a VR simulation will demonstrate greater short-term learning than students randomly selected to be in a control group. See Figure 1 for our CONSORT Diagram.

The Simulation

The simulated environment was of a hospital ward side-room with one patient in bed and an avatar that was operated by a single student (see Figure 2).

The VR simulation was created by a VR company (Daden Ltd) on a Unity 3D platform. It was based upon a deteriorating patient script created by specialist nursing colleagues. Students played the part of the nurse avatar who stayed within the ward side room. The simulation began with the nurse in charge providing the student avatar with the handover. The handover (in the form of SBAR communication) gave the nursing student knowledge about the patient's condition, current medication and observations which had been recorded the night before. The handover also detailed the patient's history, which included the fact that the patient had Type 2 diabetes and had been admitted to the ward with a chest infection and at admission had hyperglycaemia (high blood glucose). The patient later goes onto experience hypoglycaemia, and it is this that the educators hoped students would identify and treat.

The nurse in charge instructed the student to check the patient's observation chart and then carry out observations. The equipment in the room simulated nursing equipment from the local hospital. From this point the student took over the nursing care of the patient seeking advice from the nurse in charge as needed.

Student Participation

The number of students who agreed to take part in the study was 216 (81% of the total population). The sample was representative with respect to gender and age. Participants were randomly assigned to one of two groups, either the control group or the experimental group. Both groups case studies were identical and aimed to improve student nurse engagement with, and knowledge levels relating to, a diabetes and chronic illness unit of work. The control group completed a paper-based hypoglycaemia case study, whilst the experimental group completed a VR-based version of the case study. This VR exercise was authentic as possible because it was based upon the layout of the local hospital ward, through modelling props from photographs of their equipment. Both versions of the case study took comparable lengths of time to complete and both were repeated three times for learners to gain maximum benefit.

The VR simulation was fully embedded into the second-year nursing curriculum and it included a pre-brief and debrief as part of the teaching session. The session was facilitated by the lecturer and learning technologists/simulation technicians. The pre-brief informed students that in the rare case that they might feel dizzy, or nauseous, we advised them to remain seated during the simulation. We had previously tested the VR with a small group of staff to evaluate user acceptability. All students, regardless of which group they had been randomised into, were able to use the VR simulation software after the session via the University online learning platform.

Collecting and Analysing the Data

Prior to initiating the study, ethical clearance was obtained from a University Research Ethics Committee. Participants completed a consent form prior to taking part in the intervention and were fully informed about data protection and anonymity. Confidentiality and data protection measures were implemented during this study as recommended by the university. All participants received a pseudonym to guarantee that when accumulating, storing, and reporting qualitative findings, it was not possible to identify individual participants.

On obtaining written informed consent from the nursing students, an online survey was run using Online Surveys (https://www.onlinesurveys.ac.uk/) and students' own handheld devices. The design of the surveys (pre and post) was based primarily upon the partial least squares-structural equation modelling (PLS-SEM) conceptual framework which evolved as a result of the CR review of the literature. Questions were also drawn from tried and tested questionnaires, in order to optimise validity and reliability, namely the Technology Acceptance Model (Davis, 1989) and the Immersive Tendencies Questionnaire (Witmer & Singer, 1998). In total participants were asked twenty-six questions in addition to the hypoglycaemia questions (the questions are available upon request). Students completed the pretest survey one week prior to the intervention. The pretest survey consisted of ten hypoglycaemia multiple choice questions written in conjunction with diabetic nurse specialist nurses, a series of Likert scale questions for attitude questions which were linked to the conceptual framework and hypothesis, and open-ended questions to stimulate expression of experience and views about using the case studies.

Participants were invited to complete a posttest immediately after the exercise, which contained some of the same questions as the pretest (for comparison), for example, the hypoglycaemia multiple choice questions questions. This very short space between the intervention and posttest was chosen to limit students encountering any other diabetes learning in the interim. However, it is acknowledged that this means the posttest will measure any immediate surge in knowledge but will not measure any longer-term retention of learning.

To test the conceptual framework, we used a PLS-SEM procedure. We selected PLS-SEM because the approach is effective with a small sample size and non-normal data. Measurements and structural modelling were performed using Smart PLS (Version 3.0; Ringle, Wende, & Becker, 2015) software. A .05 significance level was used throughout the evaluation.

Results

Demographic Data

In total 171 students completed both the pre and posttest surveys. This was a 67% response rate. There were no missing data from the surveys. The data show that the number of respondents in the control (n = 88) and experimental group (n = 83) were comparable. The number in each group was sufficient to detect an R^2 value of at least 0.25. Forty-five participants would be needed in each group to obtain an 80% statistical power, with a 5% probability of error (Hair, Sarstedt, Ringle, & Gudergan, 2017). More females (94%) took part in the study than males (6%). More Adult nursing students took part in the study than Mental Health nursing students. Overall, the control and experimental groups were comparable in terms of gender and type of nursing being studied. When age was tested with an independent samples median test across the control and experimental groups, there was found to be no difference between groups ($p = .118$). The data show that the randomisation between groups was equal between the cohorts. In both cases more students were randomised into the control group than the experimental group.

The experimental group performed better on every question. The Experimental group scores were significantly higher ($p < .001$) than those of the control group at the .05 significance level, using an independent samples median test. Thus, the null hypothesis that medians of quiz scores are the same across categories of groups can be rejected. That is to say, the experimental group answered the posttest hypoglycaemia MCQs more accurately which is suggestive of short-term learning gain superiority in the desktop VR group. Assuming a .05 significance level, the findings were that all the relationships in the structural model were significant.

Figure 3 below shows the pathway model. The five blue circles are the variables or mechanisms, namely experience, confidence, engagement, immersion, and knowledge (EXPDIAB). The yellow rectangles show the specific survey questions that are linked to the variables, for example EXPDIAB is previous diabetic nursing experience. The yellow rectangle ITSCARED represents the immersive tendency for someone to remain scared for a period of time after watching a scary film or reading a scary book. This is relevant because it relates to how immersive a VR simulation is and consequently how effective it can be as a learning tool. The thicker arrows are more significant. The figure is useful in understanding that the variables/mechanisms are not isolated but they interact to have an effect on the target outcome, which in this case was improved short term knowledge gain.

Across the data set all pathways were found to be significant. Across the groups, confidence and knowledge scores were higher in the experimental Group. Across the

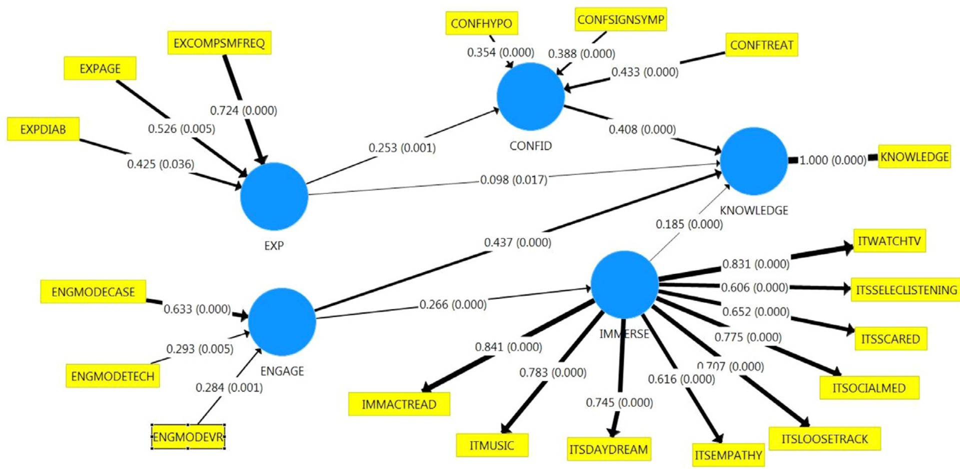

Figure 3 Conceptual framework showing pathways between the constructs (experience, confidence, engagement, immersion, and knowledge) involved when student nurses learn about hypoglycaemia using a VR simulation.

data set the engagement to knowledge pathway was partially mediated by immersion. However, across groups, the only significant pathway in the conceptual model was the engagement to knowledge pathway, which has an original difference of 0.278, which does not fall between the confidence intervals of -0.255 and 0.262. This may indicate that the improved knowledge scores for the experimental Group have resulted from this "key pathway", which could be deemed to be the "action point" of the PLS-SEM model. The latent variable 'prior experience' was not found to be significantly different between groups. This indicates that the VR simulation is an inclusive learning tool, regardless of students' age, computing experience or diabetic nursing experience.

Discussion

This study hypothesized that the experimental group would be more knowledgeable than the control group. A significant and measurable knowledge difference was found between groups in the current study, this is an unusual finding. There have been some previous researchers who have reported greater conceptual and procedural knowledge learning gains following activity with the desktop VR simulation compared to the control (Achuthan, Francis, & Diwakar, 2017; Dubovi, Levy, & Dagan, 2017). There have been few studies that have been able to support measurable learning gain (Kirkman et al., 2014); moreover, some studies have suggested that little can be established about the short-term knowledge gains acquired when using VR (Makransky, Terkildsen, & Mayer, 2019). This study, however, adds to the body of evidence in relation to VR learning and retention of knowledge because the results support the notion that VR learning can improve "short-term" knowledge gain.

Immersion was evidenced, as a contributing factor in improving knowledge when using VR simulation. This finding supports those of previous researchers (Tüzün & Özdinç, 2016). Whilst Tcha-Tokey, Christmann, Loup-Escande, Loup, and Richir (2018) suggested that engagement is the first step towards immersion, there have been few attempts to measure the strength and direction of the precise relationships between these concepts. By pairing CR with PLS-SEM, this paper has evidenced a statistically significant mediation effect of the engagement to immersion pathway that produced statistically improved knowledge gain in nursing students who learnt using VR. This means that via engaging and immersing students in their learning (e.g., experiential and visual affordances of VR) despite the software being low cost, better learning outcomes were obtained.

Results indicated that second year nursing students, regardless of their age, prior nursing, and prior computing experience, would benefit. Within previous research there has been no real commentary on the inclusive nature of VR simulations. This paper distilled aspects of inclusion, including instant feedback, visualisation aspects, individualised learning opportunities, repetition opportunities, the chance to make mistakes in a safe environment, text box information, and experiential learning. These elements added together enhanced student confidence for those who completed the deteriorating patient study via VR simulation, regardless of their prior experience and regardless of their learning needs. The results also indicated that those who had higher immersive tendencies were more likely to engage well and learn successfully from the VR tool. Hence, educators would be well advised to encourage such immersive tendencies in their students. If more VR scenarios are made available to the students, and once students have used such simulations several times, they might feel more at ease and more likely to allow themselves to become immersed within the VR.

In the scenario a clear set of clinical treatment was available (Joint Formulary Committee, 2019) for the treatment of hypoglycaemia. Conditions similar to diabetes, where clear clinical guidelines are available, might also be suitable, e.g., exacerbation of asthma, sepsis, or meningitis. Use of the original method revealed that nursing students valued the rarer opportunities to work individually in HE learning sessions. Previous research tends to highlight the collaborative affordances of VR technology (Falconer & Ortega, 2018; Tüzün & Özdinç, 2016). However, in the present study the chance to learn at the student's own pace, importance or being able to repeat the exercise until confident, and without the group pressures to select a response that they did not necessarily agree with, were valued.

The generalisability of these results is subject to certain limitations. For instance, only desktop VR was tested. Several other researchers (Makransky et al., 2019) have found that immersive VR is superior to desktop VR in training students. For example, they concluded that immersive VR is superior to desktop VR in arousing, engaging, and motivating students. However, there is no overwhelmingly conclusive evidence that immersive systems are more effective in educational applications than their non-immersive (e.g., desktop) counterparts (Ogbuanya & Onele, 2018). This study measured short term knowledge gain, which is a limitation. Future research could include a follow-up, for example after three months, this would act to evaluate if there has been any longer-term gain in knowledge.

Conclusions

This article adds to the knowledge of the potential for virtual technologies to positively affect learning in nursing education. CR, coupled with PLS-SEM was found to be a methodological approach that could enable us to understand the pathways to learning that student nurses experience when using virtual technologies, thereby adding to our knowledge about both virtual technologies in education, and about the methodological approaches that might move the evaluation field on, past its current superficial approach. This study has endeavoured to identify the underlying mechanisms and facilitating contexts that were tested in this research in order to provide a more full-bodied understanding of the variables involved. Findings indicate that whilst multiple mechanisms interact in different ways for learners, engagement leading to immersion is a key mechanism when learning using VR.

Overall, this study strengthens the idea that prior experience is not essential when learning with VR. The VR simulation was found to be an inclusive tool for teaching and learning, providing opportunities for safe practice of clinical skills. The evaluation indicates that the VR exercise was highly interactive and encouraged personalised and situational learning. The instant feedback enabled via the VR simulation, was deemed to be a clear advantage in accelerating student learning of the concepts involved in diagnosing and treating a deteriorating patient suffering from hypoglycaemia.

In this instance the immersive quality of the VR simulation can be attributed to the knowledge of diabetic nurse specialists; nurse academics with VR expertise; and an authentic scenario. Students reported thinking and acting as if they were on a hospital ward. The present study has gone some way towards enhancing our understanding of the specific mechanisms of action that interact when students learn via VR. This conclusion will be of interest to software designers and educators in encouraging them to ensure that activities they create, and use are both engaging and immersive in order to produce the best outcomes in terms of student learning.

Large-scale experimental design analysed via the robust approach (PLS-SEM) provides confidence in the results and permits the claim that the diabetes VR simulation was effective in improving student learning. This study adds to our understanding of VR use with undergraduate nursing students using deteriorating patient case studies. It is reasonable to imply that other similar student nursing cohorts would benefit from the technology created and tested through this research. Findings extend those of earlier studies and have implications for the understanding of how the mechanisms involved when using VR interact, and consequently how VR can be successfully designed and implemented for learning. VR may deliver greater access to practice opportunities in HE, spanning the gap between the formal and practical learning of professionals, a vital step in developing students' proficiency. During the Covid-19 pandemic learning was moved online in haste. In the aftermath of this pandemic, we recommend that educators take stock and examine the evidence base behind technology-based learning approaches, such as the VR clinical simulation evaluated in this study.

Conflict of Interest

The authors declare there was no conflict of interest.

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