Heliyon 11 (2025) e43360

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Is virtual simulation as effective as clinical simulation: a mixed methods study comparing knowledge acquisition, self-confidence, anxiety, and cost effectiveness

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ARTICLE INFO

Keywords:
Virtual simulation
Virtual reality
dVRS
Clinical simulation
Clinical practice
Cost effectiveness

ABSTRACT

Introduction: Desktop Virtual Reality Simulation (dVRS) is a growing trend in healthcare education. The evidence base supporting this initiative is expanding yet there is limited evidence on how dVRS compares to clinical simulation (CS). The objectives of this study were to compare dVRS to CS with knowledge acquisition, self-confidence, anxiety as primary outcomes and cost effectiveness and students' perception of dVRS as secondary outcomes.

Methods: A two-stage sequential mixed methods approach was conducted to meet the objectives. In Stage 1, a two-armed randomized controlled trial was conducted with 67 nursing students. The experimental group (n = 34) were assigned to dVRS and control group (n = 33) to CS. In Stage 2, qualitative interviews with Stage 1 participants (n = 17) explored their perceptions of dVRS.

Results: In Stage 1, mean pre and post knowledge acquisition scores were high (>80 %) across both groups but significantly higher in the control group (Mean difference (MD) = −1.6, 95 % CI (−2.5, −0.6), p = 0.02. Anxiety decreased and self-confidence increased in both groups but statistically significant differences in confidence and anxiety were observed only in the control group (MD = −0.88, 95 % CI (−1.1, −0.6), p < 0.01) and (MD = 0.55, 95 % CI (0.3, 0.7), p < 0.01) respectively. Analysis of secondary outcomes estimated difference in cost when the experimental and control groups were compared (£893 vs £2036/participant, respectively). Thematic analysis of Stage 2 qualitative data generated three themes: decision making, alignment to real-world learning, and improving the dVRS experience. Additionally, participants perceived improvements in knowledge and confidence, reported the value of the immersive aspects of dVRS, and suggested areas for improvement regarding pre-brief and debrief.

Conclusions: Across all primary outcome measures (knowledge acquisition, self-confidence and anxiety) CS was more effective, but less cost-effective, than dVRS. Moreover, dVRS was perceived to be useful and applicable as an adjunct to CS to enhance confidence, knowledge, and decision-making skills.

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https://doi.org/10.1016/j.heliyon.2025.e43360
Received 19 July 2023; Received in revised form 17 April 2025; Accepted 23 April 2025
Available online 25 April 2025

1. Introduction

Simulation-based learning is endorsed by professional regulators as a key element of practice learning which can complement or replace clinical practice [1]. It provides a setting for learners to acquire, refine and reflect on complex clinical decisions and tasks in a safe, supportive environment [2–5]. Clinical simulation is an established approach and uses part-task trainers (models of body part or structure), simulated patients and environments (role play), and integrated simulators (medium or high-fidelity manikin) led by pedagogical experts. The rapid advancement of digital technologies has led to virtual simulation (VS) becoming a core component of nursing and healthcare education [6]. Emerging approaches include immersive Virtual Reality Simulation (iVRS) and dVRS, both of which are computer-based systems incorporating multimedia programs, interactive systems, and virtual reality. While iVRS enables learners to engage in a highly immersive virtual world, dVRS allows learners to interact with a more cost effective, less immersive, 3D environment on a computer screen [7,8].

Recent research suggests dVRS is an effective approach to increase student nurses' knowledge and confidence [9–11]. Despite this, inconsistent conclusions have been observed regarding whether virtual reality simulation is as effective as conventional simulation in terms of equipping students with knowledge and self-confidence [12,13]. Moreover, limited evidence is available to evaluate the cost benefits and shortcomings of integrating virtual reality healthcare curricula. Additionally, these studies applied a variety of methods, simulation designs, and interventions to demonstrate their outcomes. However, all acknowledged that further research is required to enhance the evidence base in this area [7,14–17]. Therefore, this study aimed to address this gap by:

- comparing the effect of dVRS to CS on student nurses' knowledge acquisition, self-confidence, and anxiety
- Comparing cost effectiveness of dVRS and CS.
- Exploring student perceptions of the use of dVRS compared to CS in relation to knowledge acquisition, self-confidence, and anxiety.

Findings from this study will inform how dVRS is used in health care curricula globally. This is of particular interest where there are capacity pressures on practice learning environments, and in low- and middle-income countries where access to simulated learning spaces and equipment is limited. We hypothesised that dVRS would be as effective in knowledge acquisition and confidence, more cost-effective and students would perceive it as an effective pedagogy.

1.1. Theoretical framework

This study was underpinned by Jeffries simulation theory [18] which integrates key components of simulation-based learning, including design and development of scenarios, implementation and evaluation of learning outcomes. The theory endorses the use of best practice during design, development and implementation and how those will impact on simulation learning outcomes (students' knowledge, skill performance, self-confidence, critical thinking, and satisfaction). Evaluation involves assessing the effectiveness of the simulation-based learning activity in achieving the expected outcomes, identifying areas for improvement, and collecting feedback from the learners.

2. Materials and methods

A two-stage explanatory sequential mixed method approach was applied [19]. In Stage 1, we conducted a 2-armed randomized trial (dVRS vs CS) with pre-registration nursing students in which primary and secondary outcomes were tested: knowledge acquisition, self-confidence, anxiety and cost effectiveness. In Stage 2, we aimed to understand students' perceptions of dVRS as compared to CS.

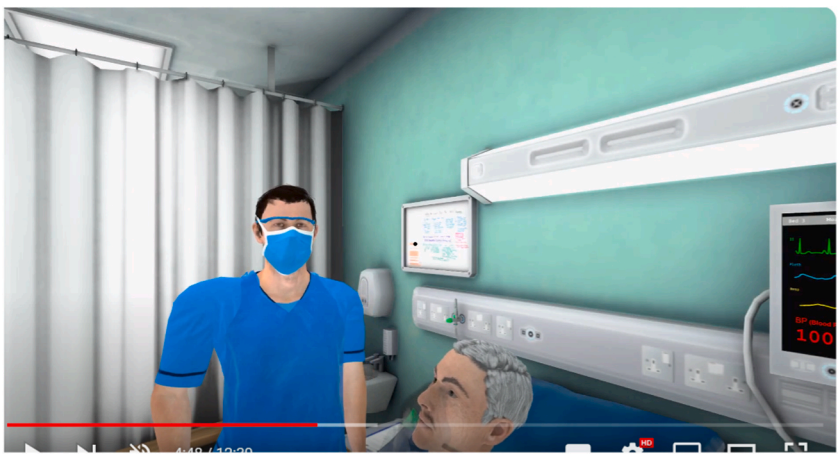

Fig. 1. The immersive desktop virtual reality simulation used in the study for facilitating clinical training.

The study was conducted from October to December 2021 at Edinburgh Napier University, Scotland.

2.1. Stage 1

2.1.1. Participants

Eligible participants were second- and third-year adult nursing students. Study information was distributed to potential participants via academic staff, email, and face to face briefing sessions. Samples were derived from a power analysis using G*Power 3.1.5 with alpha = 0.05 and power = 0.80. Using the means and SDs of previous relevant studies, with an additional 10 % for possible non-response rate, the estimated sample sizes were varied between 20 and 74 [2,20,21]. Therefore, the target sample size was 74. To increase representativeness and power and minmise sampling bias, 85 nursing students were recruited, and 67 of them completed the simulation. No further sample size adjustment was made during recruitment.

Using coin toss methodology participants were randomized to either the experimental (dVRS) or control arm (CS). A clinical scenario focusing on the assessment and management of a deteriorating respiratory patient was used in both groups. Students in the experimental arm underwent dVRS, while those in the control arm participated in an identical clinical simulation (CS). A member of the research team was present during the simulation and all participants were assigned 60 min to complete the intervention. All data were collected at the University Simulation and Clinical Skill Centre.

2.1.2. Intervention

The Healthcare Simulation Standards of Best Practice (HSSBP) were applied in the design, development, intervention, and evaluation of the virtual simulation [22–26]. The dVRS (Fig. 1) was co-produced with serious games experts in Scotland (Articise and the Scottish Centre for Enabling Technologies (SCET), at the University of West of Scotland) between 2018 and 2020 for a fixed initial purchase and 24-month maintenance cost. Intellectual property rights were retained by Edinburgh Napier University, and simulation compatibility with university software systems were considered at the outset ensuring the long-term use and scalability of the product.

The following HSSBP were adapted:

- Prebriefing: Before participating in the simulation activity, an online, interactive preparatory workbook on the management of a seriously ill person with respiratory compromise (COVID-19) was distributed to all participants. The workbook content was based on national guidance [27], reviewed by clinical experts and provided students with identical baseline knowledge before completing the simulation.
- Simulation design: The HSSBP emphasizes the significance of aligning simulation objectives with students' learning outcomes. The simulation was underpinned by international guidance [27] and reviewed by educators and clinicians. The digital aspects include interactive features, patient responses, virtual assessments (blood gas analysis, chest x ray interpretation), and medication review.
- Facilitation: The standards emphasize facilitator competence and provide them with appropriate training to guide students through the virtual simulation. Facilitators were experienced clinical educators who were provided with specific training relating to the virtual platform, use of high-fidelity manikins and effective communication skills to support students' engagement and learning. Technical support from experts was available throughout the simulation activity.
- Debriefing: Debriefing promotes learners to reflect on their simulation learning experiences. The virtual simulation incorporated features such as immediate feedback on completion of the intervention. Qualitative feedback was collected to establish if there were any improvements in the usability of dVRS.
- Assessment: Validated assessment tools to measure students' performance. Accordingly, the Nursing Anxiety and Self-Confidence with Clinical Decision Making (NASC-CDM©) scale [28], and knowledge questionnaire aligned to best clinical practice was used to measure students' performance.
- Ethics: Ethical considerations were also integral to the simulation. Hence, ethical approval was granted by the School of Health and Social Care Integrity Committee at the study institution (2780191). Moreover, participants' written consent was obtained, and privacy and confidentiality were maintained throughout.

2.1.3. Data collection

Data collection took place between October and December 2021. Baseline demographic data (age, year of study, gender) were collected, and measurement of self-confidence and anxiety used the NASC-CDM© scale, a tool developed by White et al. [28]. This tool is a 27 item, 6-point Likert scale with two sub-scales (self-confidence and anxiety). Sub-scales are rated from "1 (Not at all)" to "6 (Totally)", and, upon completion, a score is calculated. For self-confidence, higher scores indicate greater confidence, and for anxiety, lower scores mean less anxiety. Often self-efficacy has been measured as self-confidence. However, White argues that anxiety co-exists with the confidence level of students during clinical performance. Therefore, in this study, both self-confidence and anxiety scales were measured [20,28]. The NASC-CDM© was administered pre and post simulation. This tool has been proved for its validity and reliability [28]. The evaluation of convergent validity demonstrated a positive and statically significant correlations between the sub-scales of the tool and two existing instruments [28]. Furthermore, internal consistency was assessed to ensure the reliability of each subscale (self-confidence, $\alpha = 0.97$; anxiety, $\alpha = 0.96$) [28].

Knowledge of the participants was measured during the simulation using a 22-item multiple choice format instrument with a maximum score of 24 points totaled and calculated as a percentage score. It was created using the best clinical practice guidance and every item was evaluated and revised for its content validity by a team of critical care experts. It tested knowledge on key interventions related to the COVID 19 scenario, namely, 1) immediate management; vital signs, oxygen therapy and intravenous fluids [2]

requesting and interpreting investigations, for example, serum and arterial blood gas analysis, respiratory examination, and chest x-ray interpretation and [3] pharmacological and non-pharmacological interventions; antibiotics, steroid therapy, and transfer to critical care. It was evaluated for validity and reliability on a pretest of 10 % of the total sample size. Feedback on overall performance was provided to each student on completion of the scenario by a member of the research team.

The cost-effectiveness analysis was performed according to the principles in the National Institute for Health and Care Excellence (NICE) [29]. Thus, cost-effectiveness was estimated by calculating the total cost of dVRS development and academic resource to deliver and comparing this to the cost of using simulation equipment and facilities, academic resource and consumables for CS.

2.1.4. Data analysis

Data analysis was carried out using SPSS version 26. Cronbach's alpha demonstrated good internal reliability of NASC-CDM ($\alpha = 0.85$) and knowledge acquisition scales (Crohnbachs $\alpha = 0.73$).

Independent-samples T test and a paired-samples T test were performed to detect differences between the groups and within each group, respectively, at $p < 0.05$ and 95 % CI. Accordingly, independent-samples t-tests were used to compare the scores of self-confidence, anxiety, and knowledge between the experimental and control groups. Additionally, paired samples t-tests were used to compare the pre-test and post-test results of self-confidence, anxiety, and knowledge within each group. The assumptions of these tests were checked and met. Normality tests, such as the Shapiro-Wilk test and Q-Q plots, were used to assess the normality of the data, and Levene's test was used to evaluate the homogeneity of variances.

2.2. Stage 2

2.2.1. Recruitment, data collection and analysis

For the qualitative phase, we used thematic analysis, an approach which provides a systematic way of examining data to draw conclusions from the study phenomenon [30]. The research team had a clear understanding of the phenomenon and, in the qualitative phase, sought to develop an in-depth understanding of how dVRS compared to CS. This approach triangulated and integrated Stage 1 data in addition to providing a novel insight into students' perceptions of dVRS. On completion of dVRS all participants were invited to take part in Stage 2. The total sample size ($n = 17$) was estimated based on the principle of data saturation, and relied on a combination of interpretative, situated, and pragmatic judgement as recommended by Braun and Clarke (2021). Sample size considered the demographics of students who participated, the timeframe for data collection and, during analysis, evidence that no new information, themes, or codes generated from the data [31].

Online semi-structured interviews, using a topic guide (Supplemental Material Table 1), were digitally recorded. After completion of the interview, AK and RP transcribed and familiarized themselves with the data taking note of potential themes and assigned to NVIVO for analysis. Thematic analysis was then conducted by AK and verified by RP. The process included familiarisation with all the data through reading texts, listening to audio recordings, coding, and categorising into relevant data extracts, and verifying meaning with research participants where necessary. Themes were created from meaningful patterns in the data, triangulated and integrated with Stage 1 findings and analysed for new potential themes relating to how dVRS compared to CS. Validity and robustness of themes were confirmed when researchers agreed themes and verified that they were coherent, consistent, and distinctive.

3. Results

3.1. Stage 1

3.1.1. Sample characteristics

Of the 85 students initially recruited, 67 (79 %) participated in the study, 7 students (8 %) were excluded because they did not complete all stages of the study, the remaining 11 (12 %) withdrew for personal reasons. Demographic comparisons between the experimental and control groups revealed similar second (32.4 % vs 39.4 %) and third year student participation (67.6 % vs 60.6 %), similar age range between the two groups (range 18 and 55 years (Mean = 31.3, SD = 9.4) and a higher proportion of male participants in the control group (15.9 % vs 5.9 %) (Table 1).

Table 1
Characteristics of study participants.

Variable	dVRS N (%) = 34	CS N (%) = 33	X^2 P-value
Gender			0.29
Male	2 (5.9)	5 (15.1)	
Female	31 (91.1)	28 (84.9)	
Other	1 (3)		
Year of study			0.54
2nd year	11 (32.4)	13 (39.4)	
3rd year	23 (67.6)	20 (60.6)	
Age			0.54
≤30 year	19 (55.9)	16 (48.5)	
>30 year	15 (44.1)	17 (51.5)	

3.1.2. Comparisons of knowledge acquisition, self-confidence, and anxiety in the experimental and control groups

Table 2 shows knowledge acquisition, self-confidence, and anxiety scores in both groups. Knowledge acquisition was high in both groups (>80 %). Mean knowledge score for the participants in the control group was significantly higher than the intervention group, (21.4 ± 1.6 vs 19.8 ± 2.1). In both groups: gender, age, and year of study, of the students showed no statistical differences in knowledge score. Comparing experimental and control groups there were no statistically significant differences in pre and posttest self-confidence score, (MD = 0.17, 95 % CI (−0.2, 0.5)) and (MD = −0.42, 95 % CI (−0.9, 0.1)). Between groups mean anxiety scores revealed no significant (MD = 0.01, 95 % CI (−0.2, 0.3). After simulation, however, a significant statistical difference was found in the mean anxiety scores between the two groups (MD = 0.52, 95 % CI (0.1, 0.8)), with mean anxiety score in the experimental group (2.5 ± 0.8) higher than control (2.0 ± 0.5). Pre and post test scores revealed a significant increase in self-confidence (MD = −0.88, 95 % CI (−1.1, −0.6), $p < 0.01$) and a significant decrease in anxiety (MD = 0.55, 95 % CI (0.3, 0.7), $p < 0.01$) in the control but not the experimental group.

3.1.3. Cost-effectiveness

The total costs of the CS and dVRS estimated at £75,333 and £33,047, respectively. The estimated costs of the CS and dVRS appeared at £2036/participant and £893/participant, respectively (Table 3).

3.2. Stage 2

3.2.1. Triangulation

Out of 34 eligible participants in the experimental arm of the study, 17 were recruited to Stage 2. Fourteen (82.35 %) were female, and 11 (65 %) were third-year nursing students. Interviews were conducted via an online teleconferencing platform and lasted between 12 and 25 min. Following analysis of Stage 1 data we sought to triangulate and integrate Stage 1 findings and explore in more depth the effect dVRS had on knowledge, anxiety and confidence.

dVRS participants reported timely understanding of the patient's clinical signs and appropriate decision making:

> "I've gained confidence as I have a greater understanding of the signs and symptoms of someone who comes in with COVID-19 into hospital settings, I feel I know how to treat and manage a person who has COVID-19." (S1)

Four participants reported a decrease in anxiety:

> "… So if I will be in this situation in real life I will be a little bit calmer and would say gain the confidence to treat the patient.'' (S3)

Fifteen Stage 2 participants aligned with Stage 1 findings and perceived their knowledge had increased post simulation. They learned about clinical aspects of COVID-19 pneumonia, presenting symptoms and about available treatment options such as oxygen therapy, fluid, and medical management.

> " …. it goes through a lot of things, even medications ….which fluid you use. And what's important like vital signs and blood investigation of the patient? So, it's a good way of teaching." (S15)

dVRS was also found to be facilitative in the teaching-learning process.

> "Clicking on the different tabs and thinking and seeing the different options of the things I could do. So that helped me to develop my knowledge and I feel like, uh, maybe I'll retain the knowledge better." (S7)

3.2.2. Perceptions of dVRS compared to CS

Thematic analysis of Stage 2 data exploring students' perceptions of dVRS generated three themes: decision-making, alignment to

Table 2
Comparisons of knowledge acquisition, self-confidence, and anxiety in the experimental and control groups.

Variable	Pretest	Posttest	MD	CI	P-value
	M (%) (SD)	M (%) (SD)			
Paired sample *t*-test					
Self-confidence					
Experimental	3.6 (60 %) (0.7)	3.8 (63.3 %) (1.1)	−0.28	(-0.6-0.0)	0.08
Control	3.4 (56.6 %) (0.8)	4.3 (71.6 %) (0.9)	−0.88	(-1.1, −0.6)	<0.01
Anxiety					
Experimental	2.6 (43.3 %) (0.5)	2.5 (41.6 %) (0.8)	0.03	(-0.1, 0.2)	0.69
Control	2.6 (43.3 %) (0.6)	2.0 (33.3 %) (0.5)	0.55	(0.3, 0.7)	<0.01
Independent sample *t*-test					
Knowledge					
Experimental		19.8 (82.5 %) (2.1)	−1.6	(-2.5, −0.6)	0.02
Control		21.4 (89.1 %) (1.6)			

Note: T-test, level of significance at $P < 0.05$, M = mean, MD = mean difference, SD = standard deviation, CI = confidence interval.

Table 3
A comparative cost estimation.

Resources	dVRS	CS
Staff	37*(1 facilitator/10 students) *£25.30*1/2 h = £46.8	37*(1 facilitator/2 students) *25.3*1/2 h = £233.1
Laboratory room	Not necessary	Necessary
Portability	Portable	Not portable
Consumable supplies	£0	£100
Cost of game/simulator apparatus	£33,000	£75,000
Total cost	£33046.8	£75333.1
Total cost per student	£893.1	£2036.0

real-world learning and improving the dVRS experience. Definition of the themes are outlined in Supplemental Material Table 2.

3.2.2.1. Theme 1: Decision-making. Fourteen participants stated that dVRS enabled them to exercise independent decision-making.

> "So, in this simulation, it's you who's the one who's doing it, but within the practice, you don't get that authority." (S5)

Participants reported the virtual clinical area, support from the avatar, and decision-making helped to retain their decision-making skills for future reference.

> "You know, that gives me a little light in my head [about] what we can do if I have any difficult patients." (S3)

> "For me when I'm making clinical decisions, I rather view the patient as like a problem with their respiratory system ….so I'm thinking a lot about his circulation." (S7)

3.2.2.2. Theme 2: Real world learning. dVRS offered participants a safe and realistic environment where they can practice their skills without fear of making mistakes and consequences.

> "… if I clicked the wrong decision ..the computer would say, oh, I think you should try again. Which is good because if I had just written that down I wouldn't have known that I got it wrong." (S12)

Some reported dVRS was so intense that they were completely immersed in it like clinical simulation.

> "I did enjoy this actually and I kind of forgot everything else around you." (S15)

They said that dVRS was interactive, participative, and self-explanatory.

> "I found that a really good aspect because they interact in part like I had to participate." (S12)

One student stated that some practical knowledge is difficult to acquire through CS but is readily available in a dVRS.

> "Well, it's on a mannequin you can't hear the sounds of the lungs.
>
> And you'll hear on the simulation, the difference and normal lung sounds and abnormal." (S13)

Another participant thought dVRS was beneficial and closely aligned to the real-life scenario.

> "… … And potentially a suitable replacement. Certainly, you've got more time to do it, and I think the way it was structured you know, it's like you're in an actual room with people and the results, and it's fairly like what it would be like in real life in a way." (S10)

3.2.2.3. Theme 3: Reflections on dVRS. Participants' reflections reported that simulation instructions were simple and clear and a valuable and beneficial instrument for expanding their knowledge and comprehension.

> "I found it straightforward to use, even like using this space bar on the next thing. ….It's very user-friendly." (S16)

Conversely, some participants found it lacked a holistic approach along with a real time interaction with the avatar.

> "For, because it was a simulation. It didn't like seeing with a given like compassionate care and stuff like that …" (S7)

> "Maybe there could be a dialogue option where you speak to [the avatar] and you tell them what you think and they might answer." (S15)

Others reported dVRS less stressful and more convenient.

> "Well, I think it's less stressful doing it virtual than the clinical skills." (S6, T1)

> "It's a much sort of easier and quicker process than having to sort of coming into university for the day or a few hours sort of thing or whatever. Uh, and I probably have retained information just the same." (S14)

Areas for improvement were noted one participant said, *"clearer onscreen instruction may be helpful …" (S4)*

Improving feedback on completion was suggested:

".. you pick something and get it right …. when you get it wrong you need more explanation as to why they were right or wrong." (S11)

In addition, participants suggested improving the functionality of the simulation by making the cursor less sensitive:

"Listening to the patients' chest. Uhm, it was a bit difficult because the mouse would move so quickly and for the different to try and focus on the different sections. So perhaps something. You know slower mouse sensitivity or the option of putting it up or down." (S10)

Location of the multiple-choice questions in dVRS caused some confusion. A final area for improvement was application of an instructional video or subdividing some of the questions.

". .made me skip [the questions] later so it maybe it might be better if the questions were separate." (S16)

(Note: S- Student, Quotation marks are used to indicate participants' direct speech during the interview)

4. Discussion

This study sought to assess and compare the effects of dVRS and CS in a cohort of pre-registration nursing students on knowledge acquisition, self-confidence, anxiety, and cost effectiveness. As far as the authors are aware this is the first study to compare the two interventions. A notable strength of this study lies in its exploration of perceptions of dVRS and its comparison to CS.

Mean knowledge acquisition scores in the dVRS group were 19.8/24 (82.5 %). These findings were corroborated in Stage 2 results where students reported gaining valuable knowledge from dVRS. Whilst these scores were lower than CS, both groups scored greater than 80 %. This suggests that dVRS has the potential to effectively equip and prepare students for CS and clinical practice. Our findings also suggest that dVRS could be an option to gaining clinical knowledge where placement and clinical simulation opportunities are limited or exposure to complex cases are rare yet essential aspects of a curriculum [32]. Consistent with previous studies, Stage 2 findings suggested that dVRS facilitated autonomous decision-making, enabling students to lead a critical clinical event thereby fostering enhanced learning and critical thinking [33,34].

Significant improvements in confidence were observed before and after testing in the CS group, contrasting with the absences of such improvements in the dVRS groups. Moreover, anxiety scores were greater in dVRS compared to CS. Similar trends noted in Stage 2 findings where participants reported, some confidence improvement and a small subset reporting heightened anxiety. These findings are less decisive than previous research where significant improvements in self-confidence were evident after clinical simulation training [35]. Notably studies have indicated that CS has a greater effect on reducing anxiety in comparison to dVRS [15,36]. These outcomes could be linked to students' limited technical or computer skills [15] or alternatively the constraints on time to prepare students for dVRS due to ongoing COVID-19 pandemic restrictions during data collection. Furthermore, in CS, the involvement of an expert facilitator is considered best practice, providing real-time guidance, verbal and non-verbal prompts, and tailored support that fosters confidence. In contrast, dVRS is pre-programmed and although players control the pace of the simulation, scripted prompts from the avatars limit the opportunity for spontaneous clarification or advice [37]. This disparity may leave students feeling less confident and more anxious immediately after dVRS, uncertain about whether their decision making was appropriate. In our study, the posttest self-confidence and anxiety of students improved, though the changes were not statistically significant. This suggests that dVRS has the potential to enhance students' confidence and reduce anxiety if its advantages are effectively utilised. Desktop virtual reality simulation can provide opportunities for safe, independent, reflective and repetitive practice without risk to patient safety. This repetition and reflective learning process can enhance overall clinical proficiency, increase confidence and reduce anxiety [6]. Further evidence to support enhancement to dVRS is found in the qualitative findings which suggested participants may have been more confident and less anxious if greater real time support was integrated into dVRS. In response to this we have improved pre-brief instructions which include information that in-depth feedback is provided on completion of the scenario. This is consistent with two qualitative studies that recommended increasing the visual content and providing feedback to aid learning during dVRS [38,39]. In clinical simulation, pre-brief and debrief are the cornerstone of simulation best practice and create a psychologically safe space for participants [25,40]. We would therefore recommend that, during the development of future dVRS, consideration be given to how real-time multi-participant simulation, supported by an expert in simulation, could be developed and evaluated in future research. Moreover, dVRS offers a dynamic setting for skills and decision-making practice and learning, albeit with constraints, notably in terms of physical touch and development of softer skills inherent in CS. Although not achieving the same level of immersion as CS, the integration of haptic feedback systems [13], AI driven characters, and scripted interactions can enhance future dVRS design.

In the current study, the overall cost associated with the CS was approximately double that of dVRS. This is consistent with the analysis made by Hauze et al. (2019), where immersive simulation was more cost effective than conventional simulation [41]. This holds particular significance for higher education institutes given the global shortage of healthcare workers and anticipated surge in demand for health and social care education [42]. Additionally, dVRS offers extra benefits, such as the ability for students to use personal laptops, engage in repeated simulation practice, participate remotely and the absence of a need for a dedicated physical simulation space. Furthermore, higher student-to-facilitator ratios are feasible with dVRS. They are compatible with smart phone devices and, with download capability, do not require internet connection for use. Furthermore, proficiency in basic computer skills

may suffice for dVRS simulation, eliminating the need for expert guidance. Therefore, we purport that dVRS provides a sustainable and cost-effective solution to effective simulation-based education which can be shared and accessed by multiple institutions. As such, a cost-effective and global approach to developing dVRS could foster a sustainable and collaborative method for healthcare education.

This cost effective dVRS may also be beneficial for low- and middle-income countries. In fact, paucity of simulation facilities, and limited numbers of faculty with appropriate skills and knowledge to lead and develop programmes of simulation limits development in these countries. Furthermore, lack of wide availability and acceptance is still a rate limiting step for its widespread use. Studies also have indicated that participants from low-and middle-income countries were less acquainted with virtual simulation-based education [43,44]. Despite this, increases in internet access and globalization of education may be an opportunity for more widespread use of dVRS. Furthermore, research has demonstrated the benefits of dVRS in a low-resource setting for adherence to cardiac rehabilitation [45]. This suggests that dVRS is becoming an acceptable and cost-effective educational approach for health care in low-and middle-income countries.

4.1. Limitations

Whilst this study has provided some valuable insight into the application of dVRS in pre-registration nurse education, it has limitations. Recruitment took place in October 2021, which coincided with a spike in COVID-19 cases. Participants were unable to participate in the study due to self-isolation, caring responsibilities, or hesitancy to attend university. Secondly, we carried out a randomized study comparing dVRS with CS, but we acknowledge it may have been of greater benefit to include a third arm receiving classroom-based education alongside dVRS. The role of the simulation facilitator during dVRS requires further exploration. This may increase confidence, reduce anxiety, and improve the user experience. Finally, it may have had more statistical power to see the difference between groups if we had had larger sample size. This may be a consideration for future research in this area.

5. Conclusions

Our experiment demonstrated that the CS outperformed dVRS in nursing students' knowledge acquisition, although both groups showed improvements. Significant improvements of students' self-confidence and anxiety were observed from pretest to post-test in the CS group. Conversely, while there were improvements in self-confidence and anxiety in the dVRS, no statistically significant differences were observed between pre and post intervention tests. Importantly, dVRS is more cost-effective than CS. In conclusion, while CS might currently offer superior outcomes in knowledge acquisition, confidence, and anxiety reduction, dVRS provides a more cost-effective alternative with substantial benefits and positive student reception. Nursing educational institutions should consider integrating dVRS into their curriculum, particularly where budget constraints exist, and focus on improving its preparatory and debriefing components to enhance its effectiveness. Therefore, integration of dVRS into pre-registration nursing curriculum can serve as a valuable adjunct to clinical practice and traditional simulation. Additionally, we found no study evaluating the cost-effectiveness of dVRS for simulation in nursing education. Further large-scale research, that takes the limitations of this study into consideration, is essential to develop and evaluate cost-effective dVRS in improving knowledge, confidence and reducing anxiety in an emergency simulation.

CRediT authorship contribution statement

Gdiom Gebreheat: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Anu Koju:** Writing – review & editing, Visualization, Validation, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Jane Whitehorn:** Writing – review & editing, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Jamie Lee Fairholm:** Writing – review & editing, Visualization, Validation, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Craig Shepherd:** Writing – review & editing, Visualization, Validation, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Ruth Paterson:** Writing – review & editing, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Ethics statement

Ethical approval was granted by the School of Health and Social Care Integrity Committee at Edinburgh Napier University (approval number: 2780191) on July 16, 2021, as stated in the approval letter. Furthermore, all participants provided written informed consent to participate in the study.

Data availability statement

The data associated with the study has not been deposited into a publicly available repository. Data will be made available on reasonable request.

Funding sources

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We acknowledge Edinburgh Napier University for allowing us to conduct this project.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2025.e43360.

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