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EFFECT OF CLINICAL VIRTUAL SIMULATION ON SELF-DIRECTED LEARNING ABILITY AND KNOWLEDGE RETENTION AMONG NURSING STUDENTS IN CHINA

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ABSTRACT

Background Clinical Virtual Simulation (CVS) is a relatively new teaching approach in nursing education. However, in-depth longitudinal research on learning ability and knowledge retention is lacking. This study aims to identify the effect of CVS on self-directed learning ability and knowledge retention among nursing students in China. This work is a quasi-experimental study that was conducted in two months. Sophomore nursing students from Xi'an Fanyi University were divided into two groups: The control group (n = 43), in which the traditional teaching method was used and the experimental group (n = 41), in which a combination of traditional teaching and CVS was employed. The students in the control group attended a theoretical course, followed by clinical practice courses, and received practice guidance in a laboratory. The students in the experimental group attended a theoretical course, learned and practised the simulation project on a virtual simulation platform, then, attended clinical practice courses and received practice guidance in a laboratory. The research duration was one month. The knowledge retention of the students was assessed immediately, two weeks and one month after the intervention using a multiple-choice test. The self-rating scale of self-directed learning ability was used to determine the self-directed learning ability of the students. Statistically significant improvements were observed in the knowledge retention and self-directed learning ability ($p < 0.05$) of the students in the experimental group compared with those in the control group. It is concluded that the application of CVS can enhance the memory and retention of theoretical knowledge and improve the self-directed learning ability of nursing students.

Introduction

The teaching methods of nursing education became more diverse with the rapid development of information teaching and new modes such as mixed "online and offline" teaching models, massive open online courses, and virtual reality classes for college students are gradually being applied (Chen *et al*., 2020; Kai-na *et al*., 2022; Huang *et al*., 2023). Among numerous new nursing teaching methods, CVS meets the demand for practical teaching that can be conducted online.

Because of the COVID-19 pandemic, teachers are forced to switch to online teaching even without adequate preparation and design to ensure routine delivery of lessons. Online nursing education requires more systematic and thoughtful teaching approaches as soon as possible (Morin, 2020). Conventional teaching methods refer to a combination of theoretical learning and clinical practice to deepen students' understanding and application of nursing knowledge. However, students who learn in an environment with no opportunities for direct participation in actual training may have poor knowledge retention (Kawasaki *et al*., 2022). Improvement of knowledge retention and self-directed learning has been proven to be an effective method in nursing education (Lee *et al*., 2020).

CVS involves a virtual environment where students can engage in the immersive self-regulated learning of clinical nursing practices. Such simulations can provide nursing students with a safe, dynamic, and enjoyable learning environment and hospital experience through their computers (Tinôco *et al*., 2021). CVS can also provide students with a holistic learning experience and completely immerse them in emotional scenes to improve their practical skills (Wang *et al*., 2015; Plotzky *et al*., 2021). Some studies added practical teaching content based on virtual experiments to certain open online courses (Waldrop, 2013). During the COVID-19 pandemic, Chinese universities opened thousands of CVS experiments online to ensure the normal development of experimental teaching (Yang *et al*., 2020).

CVS is extensively employed in anaesthesia care, maternal and infant care, basic nursing, and other clinical practices. It is widely used by nursing undergraduates, postgraduates, and registered nurses (Li *et al*., 2017). Previous studies demonstrated the effectiveness of CVS in improving the skills, cognition, and emotions of nursing students and it has been reported that simulation teaching is more effective than traditional teaching in developing nursing abilities (Nascimento *et al*., 2020; Shorey & Ng, 2021; Kuruca & Dinc, 2022).

However, in-depth longitudinal research on knowledge retention is lacking (Foronda *et al*., 2020). CVS in the field of nursing education in China is in the initial stage and research on whether the use of CVS can improve students' memory and prolong their knowledge retention is scarce. Thus, future research is necessary to validate the effectiveness of CVS in various aspects (Wang *et al*., 2020).

This study aims to determine the effect of CVS (integration of theoretical knowledge with clinical practice) on self-directed learning ability and knowledge retention as compared with traditional teaching methods.

Literature Review

The long history of simulation can be traced back to aviation and military applications. The flight simulator was first used in 1920. Simulated war games were also originally developed on large computer systems designed for military applications (Aebersold, 2016). When pioneer David Gaba applied aviation crew resource management to anaesthesia courses, it was the first time that simulation was used in medical education. From standardised patient to Resusci Annie to computer-based, simulation is widely used in nursing education (Rosen, 2008).

During inclement weather, the emergence of simulators can recognise the need to protect the safety of pilots and crew. Just like in nursing education, nursing students use virtual simulations to meet patient safety needs. It has been suggested that telehealth will be an important part of future clinical practice (Wijesooriya *et al*., 2020). Computer-based programmes translate what students have learned into positive experiences in the simulation laboratory (Donovan *et al*., 2018).

Simulation-based learning (SBL) has become an established teaching method for teaching clinical nursing skills (Sundler *et al*., 2015). SBL is a framework of system constructivism with a learner-centred and problem-oriented learning environment to participate in the learning process and develop an understanding of reality (Kriz, 2010). The currently common SBL methods are high-fidelity simulation (HFS) and virtual-reality simulation (VRS) (Hanshaw & Dickerson, 2020). The main types of VRS are desktop virtual simulation and immersive VR. Desktop virtual simulation involves interacting with the virtual world using computing devices such as a monitor, mouse, and touchpad. Immersive VR is the use of sensory devices such as a head-mounted display, to provide auditory and visual stimulation during an immersive VR experience (Choi *et al*., 2016). While using the desktop virtual simulation, physical discomfort such as dizziness, that occurs in the immersive VR is reduced while providing an interesting and immersive learning experience (Birbara *et al*., 2020). Desktop virtual simulation is just as effective as face-to-face simulation (Liaw *et al*., 2023). Studies have shown that the effect of using desktop virtual simulation is location-independent and that use at home is just as effective as in class (Makransky *et al*., 2019).

CVS is a kind of desktop virtual simulation that lends itself to the teaching of clinical practice. Although VRS is now widely used, the equipment required to operate CVS is simpler and cheaper than immersive VR and can be used on a large scale without limiting the number of users and location (Bueckle *et al*., 2021). CVS has had extensive applications such as anaesthesia care, maternal and infant care, basic nursing, and other clinical practices, widely used by nursing undergraduates, postgraduate nursing students, and nurse practitioners (Warren *et al*., 2016). The research direction should be more focused on helping nursing students better retain their knowledge (Tamilselvan *et al.*, 2023). This study also proposes a longitudinal study of the learning retention generated by CVS to improve the scientific level of virtual clinical practice (Foronda *et al*., 2020).

In light of these promising results, the researcher would evaluate the effect of knowledge retention with a prospective research method. Self-directed learning is closely related to active experimentation (Svein, 2020). Self-directed learning ability is very important for improving knowledge and skills, it is also an important part of lifelong learning in career development (Wong *et al*., 2021). This review summarises the results of 18 studies that test the effectiveness of using virtual tools to achieve three learning results: Nursing students and registered nurses skills, cognition, and emotion (Shorey & Ng, 2021). CVS is a relatively new teaching approach that has improved student learning outcomes in nursing education. CVS in the field of nursing education in China is in the initial stage. Thus, future research is necessary to validate the effectiveness of CVS in various aspects (Wang *et al*., 2020).

Methodology

Study Design and Setting

The design of this study is an interventional study, a quasi-experimental study design using CVS as an intervention. The objective was to evaluate the effectiveness of the CVS. An experimental design was applied using a quantitative method to evaluate the effectiveness of the intervention. Given that the population in this study comprises registered nursing sophomore students, it has been evenly divided into classes according to their admission grades.

In the process of grouping, random allocation cannot be achieved. Thus, the quasi-experimental research design is adopted. The inclusion criteria for participation are as follows: (1) Students who have completed the theoretical courses, (2) students who participated voluntarily, (3) students who agreed to complete the questionnaires and assessments, and (4) students who have not previously participated in a CVS project. The exclusion criteria included the following: (1) Students who were sick/unwell during the data collection process and (2) students who have participated in a CVS project.

Sample Size Determination

The required sample size was analysed using G*Power 3.1.9.7, T-tests, the difference between two independent means (two groups), two-tail, effect size d = 0.8 (Cohen, 1988), and Power ($1 - \beta$ err prob) = 0.9, α err prob = 0.05, allocation ratio N2/N1 = 1; calculating that the sample size was 26 for each group, the total sample size is 68. The dropout rate is 30% (20) and the final sample size is 88 participants.

Blinding

The researcher recruited participants by giving briefings to nursing students at the university to introduce the project and invite students to participate voluntarily. The investigator obtained the participants' informed consent and informed them that their participation in the study would not affect regular teaching activities and be included in the final exam assessment. The participants' student ID number was used during the intervention and the participants did not know which group they would be placed in before the actual segregation into the two groups. The same lecturer, textbook, and tests were used for the control group and experimental group to prevent group bias in this research. The basic nursing lecturer was in charge of the project and clinical practice teaching and an engineer from the company behind the CVS platform was responsible for the training on using the CVS technology and technical support. The entire research process was supervised by a supervisor.

Instruments

Two nursing lecturers at Xi'an FanYi University created a test paper on nasal feeding techniques to assess students' learning outcomes. The test content is based on the fundamental nursing teaching syllabus. Four professors reviewed the test content and the final result of this test was applicable. This test has 10 multiple-choice questions, each with only one option for the correct answer. Each question is worth 10 points, the total score is 100 points, and the test time is 15 minutes (Appendix B). Higher scores indicate that students have higher theoretical knowledge of nasal feeding techniques. Pilot testing was conducted by recruiting 28 nursing students who did not participate in this study project.

After undergoing the nasal feeding theory course, the participants were assessed using this test. The pilot study result showed that the 28 nursing students scored a maximum of 100 points, a minimum of 50 points, and a mean score of 77.58 points. This test is moderately difficult and students use the Chinese version of the test. The online mode was adopted for the test and the students were required to take the test in the classroom, under the watchful eye of an invigilator. The students used their mobile phones to scan the QR code of the test and were not allowed to close the mobile test page while answering the questions. The questions in each test were the same, but the order of the questions and options was different. The same test was used for the subsequent assessments, but the order of the options and questions was rearranged.

This study utilised the self-rating scale of self-directed learning (SRSSDL) to measure nursing students' self-directed learning ability when using CVS (Williamson, 2007). It consists of five domains: Learning consciousness, learning behaviour, learning strategy, learning evaluation, and interpersonal skills. Each dimension of the scale included 12 entries/questions, for a total of 60 entries/questions, scored on a five-point Likert scale. The Chinese version of the SRSSDL, which was translated by Shen Wangqin, demonstrated satisfactory reliability and validity, with an internal consistency reliability of 0.966 (Shen & Hu, 2011).

Study Protocol

The participants were divided into two groups: The control group, in which the traditional teaching method was used and the experimental group, in which a combination of traditional teaching and CVS was employed. The same lecturer, textbook, and tests were used for the control and experimental groups to prevent group bias in this research.

For this study, the sixth edition of Fundamental Nursing, published by the People's Health Press Chapter 11, Diet and Nutrition (Li & Shang, 2017) was utilised as the learning content. Figure 1 presents a flowchart of the experimental intervention. The students in the two groups attended a theoretical course (90 minutes) on the same day. According to the fundamental nursing syllabus requirements, the students must listen to the lecturer's theoretical lesson on a nasal feeding technique and immediately take a pre-intervention test after the class.

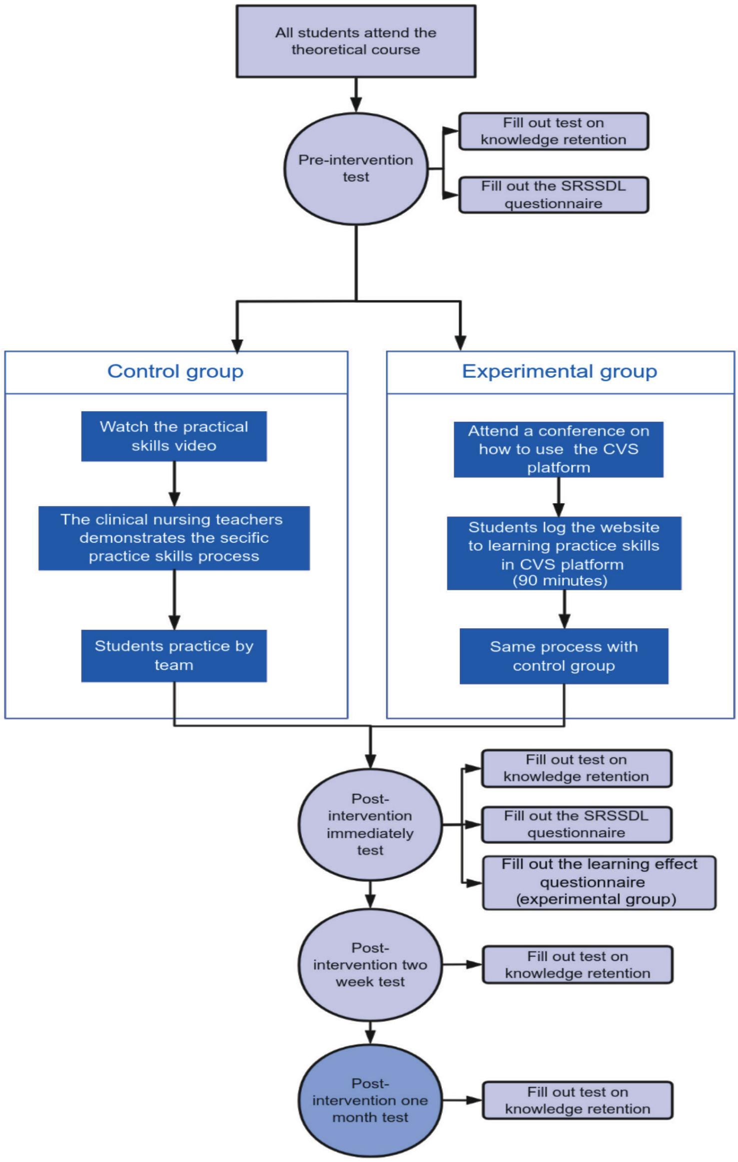

Figure 1: Process of the study

Experimental Group

After attending the theoretical course, the students in the experimental group needed to learn and practice a simulation project online on a virtual simulation platform. They then attended clinical practice courses and received practice guidance in a laboratory.

The students in the experimental group were required to attend five to 10 minutes of training on the use of the CVS platform, which was conducted by the company's staff that provided the platform. The clinic's virtual simulation platform was available only to the experimental group and the simulation project used for the group was the nasal feeding technique. On the same day, the students in the experimental group were instructed to log in to the CVS platform of the Medical Virtual Simulation Experimental Centre of Xi'an Fanyi University from their computer-equipped classroom. The students were given a personal account and unique password to log on to the website and independently study the nasal feeding technique using the clinic virtual simulation, which can be repeated to practice their skills.

The traditional teaching method was employed in the fundamental nursing training class of the students in the experimental group. In the fundamental nursing training class, students were divided into groups of four people. First, the lecturer showed the students a video on nasal feeding operations. Second, the lecturer demonstrated the nasal feeding process and highlighted the operation points and difficulties. Third, the students practised the technique in teams and the lecturer observed the students and provided guidance. Last, the lecturer gave a test on the technique. Both groups were tested again two weeks and one month after the intervention.

Immediately after the intervention, students in experimental groups filled out the test on knowledge retention and the self-directed learning ability (SRSSDL) questionnaire. Tests on knowledge retention were filled out in experimental groups two weeks after the intervention and one month after the intervention.

Control Group

The traditional teaching method was used for the students in the control group, who attended the theoretical course, attended clinical practice courses, and finally received practice guidance in a laboratory.

In the fundamental nursing training class, students were divided into groups of four. First, the lecturer showed the students a video on nasal feeding operations. Second, the lecturer demonstrated the nasal feeding process and highlighted the operation points and difficulties. Third, the students practised the technique in teams and the lecturer observed the class and provided guidance. Last, the lecturer gave a test on the technique and filled out the self-directed learning ability (SRSSDL) questionnaire. The control group was tested again two weeks and one month after using the traditional method.

Data Analysis

All the data obtained in this study were statistically analysed using IBM SPSS Statistics26. For the descriptive analysis, the measurement data were expressed as means (standard deviations) and the classification data were expressed as frequency and percentages. Data at $p < 0.05$ were considered to be statistically significant.

The Shapiro-Wilk showed that the age data were normally distributed ($p > 0.05$). The retention time data and the self-directed learning ability are not normally distributed. The central limit theorem indicates that the mean of a sample size > 30 is students using the variance and a normal distribution can be used for the probability distribution (Kwak & Kim, 2017). For the knowledge retention test, the repeated measure ANOVA test data analysis method was used according to the central limit theorem. The nonparametric test, Mann–Whitney U, compared two groups of independent samples for self-directed learning ability.

Ethical Consideration

This study was conducted at Xi'an Fanyi University and the data were obtained from the Medical Virtual Simulation Experimental Centre of the university. This study was approved by the Medical Ethics Committee of Xi'an Fanyi University and JEPeM Universiti Sains Malaysia. The study protocol code is USM/JEPeM/22090628.

Results

A total of 88 students agreed to participate in this two months study and voluntarily signed the informed consent form. Participants who were sick or unwell during the data collection were excluded from the study. A total of 84 students ultimately participated in this study, who were divided into an experimental group (n = 41) and a control group (n = 43). Figure 2 shows the flowchart of the study selection process. 41 questionnaires were distributed by the experimental group and 43 by the control group, for a total of 84. When the questionnaires were returned, 41 were received by the experimental group, 39 by the control group, and 80 were recovered, with an effective recovery rate of 95.24%.

The sociodemographic characteristics of the control group and experimental group are shown in Table 1. The mean age of the students in the experimental group was 19.91 years and the mean age of the students in the control group was 20 years. The proportion of male and female students in the experimental and control groups was roughly equal.

At the baseline data, before the implementation of the experimental CVS, there was no statistically significant difference in the test of knowledge and self-directed learning ability between the experimental and control groups (Table 2). The mean score of pre-intervention test knowledge retention scores

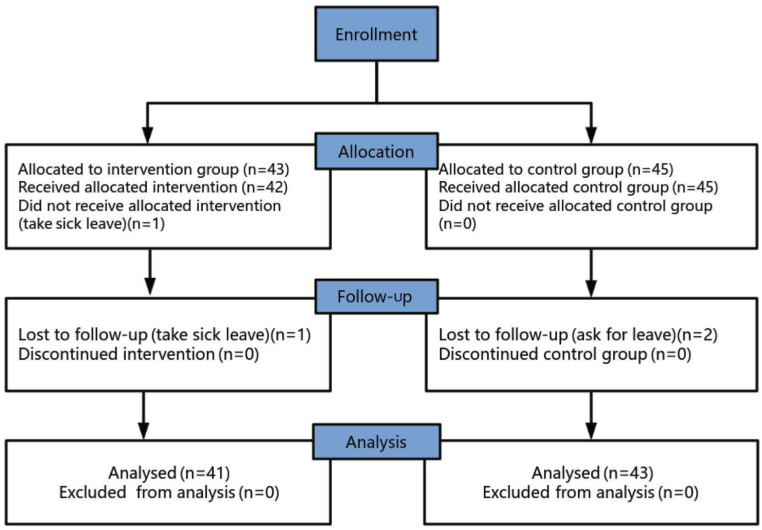

Figure 2: The flowchart of the study selection process

Table 1: Sociodemographic characteristics of respondents in the experimental and control groups (n = 84)

Variables	Experimental Group (N = 41) Mean (SD) or n (%)	Control Group (N = 43) Mean (SD) or n (%)	χ^2	*p*-value
Age	19.91(0.921)	20(0.978)	5.977	0.201
Sex			0.026	0.872
Male	8(19.5%)	9(20.9%)		
Female	33(80.5%)	34(79.1%)		

Table 2: Comparisons of test scores for knowledge and self-directed learning ability at the baseline between experimental and control groups (n = 84)

Study Variables	Experimental Group (n = 41) Mean (SD)	Control Group (n = 43) Mean (SD)	z	*p*-value
Test score of knowledge	82.19 (14.41)	76.27 (16.48)	1.71	0.087
Self-directed learning ability score	190 (180-225)	192 (181-226)	-0.14	0.889

for the control group is 76.27 (16.47). The mean score of pre-intervention test knowledge retention scores for the experimental group is 82.19 (14.40). The nonparametric Mann–Whitney U test results for the experimental and control groups are z =—1.71, $p = 0.087 > 0.05$, indicating no statistically significant difference. This shows that both groups have similar characteristics before the intervention begins.

84 nursing students participated in this experiment and 41 of them in the experimental group were tested on knowledge for assessment of knowledge retention time. Table 3 shows the result of the knowledge score before intervention (M = 82.20, SD = 14.41), immediately (M = 92.68, SD = 8.67), two weeks (M = 88.54, SD = 13.52), and one month after intervention (M = 89.27, SD = 13.11). Similar to 43 students in the control group, they were tested on knowledge for assessment of knowledge retention time. The result is shown in the table as before intervention (M = 76.28, SD = 16.48), immediately after intervention (M = 79.53, SD = 16.90), two weeks after intervention (M = 82.09, SD = 15.05), and one month after intervention (M = 79.53, SD = 14.95).

Repeated measure ANOVA was performed to evaluate the effect of the CVS combined method on knowledge retention time. The mean and standard deviation of the score of knowledge retention are presented in Table 4.3. Mauchly's test indicated that the assumption of sphericity had been met, $\chi2 = 9.44$, $p = 0.093$. The effect of CVS combined with traditional methods on the score of knowledge retention was significant at the 0.05 level, F (3, 246) = 3.97, $p = 0.009$, partial $\eta2 = 0.046$ (Table 4).

Post-hoc pairwise comparisons with a Bonferroni adjustment indicated that there was no significant difference between the score of knowledge retention at the pre-test and at the follow-up assessment two weeks later ($p = 0.102$). Similarly, there was no significant difference between the score of knowledge retention at the pre-test and at the follow-up assessment one month after ($p = 0.152$). There was no significant difference between the score of knowledge retention at the follow-up assessment immediately later and at the follow-up assessment two weeks later ($p = 1.000$). There was no significant difference between the score of knowledge retention at the follow-up assessment immediately later and at the follow-up assessment one month later ($p = 1.000$). There was no significant difference between the score of knowledge retention at the follow-up assessment two weeks later and at the follow-up assessment one month later ($p = 1.000$). However, the score of knowledge retention was significantly different at the pre-

Table 3: Description of knowledge retention scores between intervention and control groups (*n* = 84)

Condition	*n*	Pre-test	Immediate	2 Weeks After	1 Month After
		Mean (SD)	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**
Traditional	1	76.28 (16.48)	79.53(16.90)	82.09(15.05)	79.53(14.95)
Intervention	3	82.20 (14.41)	92.68(8.67)	88.54(13.52)	89.27(13.11)

Table 4: Mixed ANOVA results for knowledge retention (*n* = 84)

Effect	F	df	*p*-value	Partial η²
Time	3.97	3	0.009	.046
Condition	30.00	1	0.000	0.27
Time × Condition Interaction	1.16	3	0.326	.014

F: F-statistic from the Mixed ANOVA test.
df: Degrees of freedom (within-group and between-group).
Partial η²: Effect size measure, with values closer to 0.01, 0.06, and 0.14 indicating small, medium, and large effects, respectively.

test and at the follow-up assessment immediately after (p = 0.030) (Table 5).

Figure 3 shows the interaction line chart of two factors. It can be seen that the experimental group had good test scores compared with the control group. The self-directed learning ability of the nursing students in the experimental and control groups before and after the intervention is presented in Table 6. The nonparametric Mann–Whitney U test was conducted between the two groups before the intervention and $p > 0.05$ was not statistically significant. It can be concluded that there was no statistical difference between the two groups before the intervention. The nonparametric Mann–Whitney U test was conducted between the two groups after

Table 5: Post Hoc comparisons of knowledge retention by time and condition (Bonferroni Adjustment)

Comparison	Mean Difference	Standard Error	95% Confidence Interval for Difference[b]		*p*-value
Traditional teaching (control group)			LowerBound	UpperBound	
Pre-test vs. immediate	-3.26	3.42	-12.39	5.88	1.000
Pre-test vs. two weeks after	-5.81	3.42	-14.95	3.32	.547
Pre-test vs. one month after	-3.26	3.42	-12.39	5.88	1.000
Immediate vs. two weeks after	-2.56	3.42	-11.69	6.58	1.000
Immediate vs. one month after	.000	3.42	-9.14	9.14	1.000
Two weeks after vs. one month after	2.56	3.42	-6.58	11.69	1.000
CVS (experimental group)			LowerBound	UpperBound	
Pre-test vs. immediate	-10.49*	2.79	-17.94	-3.04	.001
Pre-test vs. two weeks after	-6.34	2.79	-13.79	1.11	.146
Pre-test vs. one month after	-7.07	2.79	-14.52	.38	.073
Immediate vs. two weeks after	4.15	2.79	-3.30	11.59	.834
Immediate vs. one month after	3.42	2.79	-4.03	10.86	1.000
Two weeks after vs. one month after	-.73	2.79	-8.18	6.72	1.000

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Bonferroni.

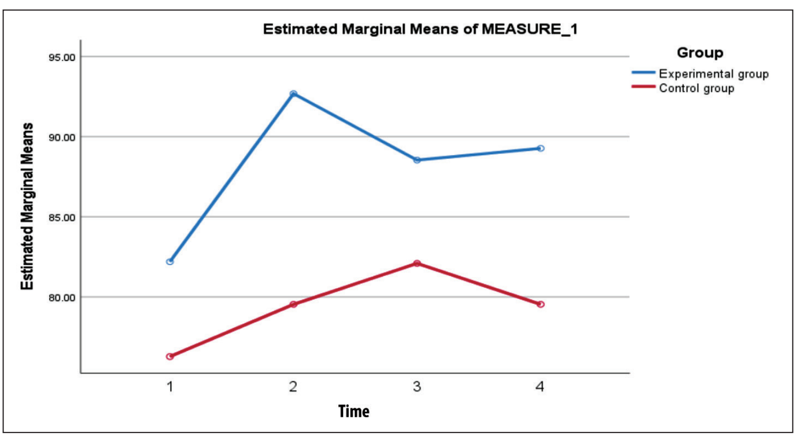

Figure 3: The interaction line chart

Table 6: Comparison of the SRSSDL questionnaire scores between the intervention and control groups before and after intervention ($n = 80$)

	Pre-intervention				Post-intervention			
	Control Group ($n = 39$)	Experimental Group ($n = 41$)	z	*p*-value	Control Group ($n = 39$)	Experimental Group ($n = 41$)	z	*p*-value
Learning consciousness	40(36-48)	40(36.5-45)	-0.581	0.561	40(36-45)	44(40.5-47)	-2.067	0.039
Learning strategy	39(36-46)	38(36-45)	-0.481	0.631	39(36-45)	46(36-48)	-2.322	0.020
Learning behaviour	38(36-45)	36(36-46.5)	-0.380	0.704	38(36-43)	44(39.5-48)	-2.944	0.003
Learning evaluation	38(36-45)	38(36-46.5)	-0.054	0.957	37(36-44)	46(38.5-48)	-2.994	0.003
Interpersonal skills	37(36-46)	37(36-47)	-0.138	0.890	41(36-45)	46(37-48)	-2.338	0.019
Total scores	190(180-225)	192(181-226)	-0.140	0.889	194(181-221)	222(196.5-238)	-2.634	0.008

intervention and $p < 0.05$, it is statistically significant. It can be concluded that there is a statistical difference between the two groups after the intervention.

The self-directed learning ability of the students in the experimental group before and after the intervention is reported in Table 7. The nonparametric Wilcoxon Signed Ranks Test was conducted before and after intervention in the experimental group and $p < 0.05$ and statistically significant. It can be considered that there is a statistical difference between the before and after interventions in the experimental group.

The self-directed learning ability of the students in the control group before and after the intervention is reported in Table 8. The nonparametric Wilcoxon Signed Ranks Test was conducted before and after intervention in the control group and $p > 0.05$ was not statistically significant. It can be considered that there is no statistical difference before and after intervention in the control group.

Discussion

This study used knowledge tests and a questionnaire and conducted data analysis to explore the effect of CVS on the knowledge retention and the self-directed learning ability of nursing students. The results showed that CVS can affect students' knowledge retention and self-directed learning ability.

Applying CVS in traditional nursing education can enhance the retention of theoretical knowledge and students' memory. Through its use of rich animation and the exploratory-type mode for practising the operation, CVS can improve knowledge retention compared with traditional training courses immediately after the intervention. In the assessment two weeks after the intervention, the students in the experimental group demonstrated a decline in their knowledge retention, perhaps because of the rich simulation that was not actually related to the operation.

Table 7: Comparison of the SRSSDL questionnaire scores before and after intervention in experimental groups ($n = 41$)

Test Statistics[a]						
	Learning Consciousness	**Learning Strategy**	**Learning Behaviour**	**Learning Evaluation**	**Interpersonal Skills**	**Total Scores**
Z	-3.318[b]	-2.679[b]	-2.794[b]	-3.073[b]	-2.685[b]	-3.162[b]
Asymp. Sig. (2-tailed)	.001	.007	.005	.002	.007	.002

a. Wilcoxon Signed Ranks Test.
b. Based on negative ranks.

Table 8: Comparison of the SRSSDL questionnaire scores before and after intervention in control groups ($n = 39$)

Test Statistics[a]						
	Learning Consciousness	**Learning Strategy**	**Learning Behaviour**	**Learning Evaluation**	**Interpersonal Skills**	**Total Scores**
Z	-.015[b]	-.218[c]	-.086[c]	-.110[b]	-.616[c]	-.203[c]
Asymp. Sig. (2-tailed)	.988	.828	.932	.912	.538	.839

a. Wilcoxon Signed Ranks Test.
b. Based on positive ranks.
c. Based on negative ranks.

One month after the intervention, the knowledge retention level of the students in the experimental group remained stable, whereas that of the students in the control group exhibited a decline. Thus, CVS improved the students' knowledge retention compared with traditional teaching immediately, two weeks, and one month after the intervention. This finding is consistent with the results of other studies (Padilha *et al.*, 2019), which can be attributed to the use of rich and vivid animation and the task-style operation process in CVS, which can enrich students' vision, vividly display the rigid knowledge, increase the coherence of the whole nursing operation, and improve students' knowledge retention.

The clinical practice requirements of the nursing profession are very strict owing to the nature of the discipline and laboratory rules and regulations are complex. Laboratory management requires a large number of staffs and the use of experimental materials and apparatus also has strict requirements. CVS can overcome the limitations of location and time and substantially save laboratory resources. Students can also operate independently anytime and anywhere using CVS. In addition, the technology can be used as an auxiliary teaching method to assist students in online learning (Smith & Hamilton, 2015). CVS is a fast and convenient way to conduct simulation experiments and can be used in multiple learning stages, including hospital internships, in which students tend to forget theoretical knowledge. It also assists students in knowledge preparation and recall. Moreover, the application of CVS can be extended to nursing students who are about to take their registered nurse exam, interns, and medical students to improve their knowledge retention.

This study showed that nursing students can use CVS to improve their self-directed learning ability, which is consistent with the results of previous studies (Liu *et al.*, 2019; Coyne *et al.*, 2021; Yeo & Jang, 2023). Specifically, the game-style operation mode can considerably improve students' self-directed learning ability. The results of this study revealed that CVS can improve students' learning consciousness, learning behaviour, learning strategy, learning evaluation ability, and interpersonal skills. In the future, nursing education teachers can assist students in using clinical virtual simulations and provide individualised tutoring based on students' self-directed learning ability. The development of online CVS platforms has implications for medical education. Nonmedical students can gain medical knowledge on topics of interest through online CVS platforms. Furthermore, common rescue techniques such as cardiopulmonary resuscitation can be learned and practised online independently, which can decrease the workload of laboratories.

This study has several limitations. For example, the study was conducted for only one semester, the sample size was small and the follow-up time was short. A long follow-up period is necessary to explore the long-term effect of CVS on knowledge retention. Furthermore, the utilisation of CVS by teachers should be explored further.

Clinical Implications

As the development and promotion of online CVS increase, researchers can deeply examine nursing students' knowledge retention and other influencing factors, including the frequency of CVS use, students' individual interests, CVS platform design, simulation diversity, and so on, to improve the utilisation and effectivity rates of the technology.

Conclusions

The results of this study indicate that the use of CVS can improve memory and the retention of theoretical knowledge. Moreover, as a new teaching model, CVS can improve nursing students' self-directed learning ability and enrich nursing education dissemination techniques. In the face of increasing online education platforms and mobile phones, the intelligent application of CVS can fill the gap in online nursing operation technology. Thus, CVS has considerable use value and potential in nursing education.

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Conflict of Interest Statement

The authors agree that this research was conducted in the absence of any self-benefits, commercial, or financial conflicts and declare absence of conflicting interests with the funders.

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