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The efficacy of virtual reality flipped learning with collaborative role-playing in nursing education

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Abstract

Background Critical thinking is a fundamental yet overlooked skill of nursing education, crucial for equipping future nurses to navigate complex clinical scenarios. Nonetheless, conventional learning methods often emphasize individual learning modes, thereby neglecting collaborative opportunities such as teamwork and role-playing. Also, traditional nursing education focuses on the training of hands-on practice, but the lack of contextualized learning through clinical scenario simulation limits the development of critical thinking, ultimately hindering the full potential of nursing education. This study aimed to assess the effects of a Collaborative Role Playing-Based Virtual Reality Flipped Learning (CRP-based VR-FL) approach in nursing education.

Methods A mixed-methods quasi-experimental study enrolled 133 nursing students via class-matching. CRP-based and non-CRP VR-FL methods were compared over a one-month intravenous (IV) infusion training programme. The research evaluated the impact of these instructional strategies on students' learning achievement and critical thinking skills by administering pre- and post-tests on knowledge related to IV infusions, a pre- and post-test critical thinking tendencies questionnaire, and a self-assessment.

Results The CRP-based VR-FL approach significantly improved IV infusion knowledge ($p < 0.05$) and critical thinking, particularly in decision-making ($p < 0.05$), though attitudinal differences were non-significant ($p > 0.1$). Furthermore, based on the students' self-assessments, it is evident that this method significantly enhanced students' learning experiences, including engagement, participation, teamwork, and independent learning skills.

Conclusion Consequently, it is recommended that nursing education actively pursue and implement the CRP-based VR-FL approach to cultivate high-quality nursing professionals.

Keywords Role playing, Virtual reality, Flipped classroom, Critical thinking, Infusions, Intravenous, Nursing education

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Introduction

Critical thinking (CT)—defined as a tripartite construct that integrates attitudes, knowledge, and skills [1]—is essential for nurses as they navigate complex clinical scenarios and prioritize patient care [2, 3]. In contemporary nursing practice, CT goes beyond mere procedural tasks, facilitating the synthesis of multifaceted information, fostering innovation in problem-solving, and enhancing patient outcomes [4, 5].

Traditional nursing education, which relies heavily on didactic teaching, clinical simulations, and hands-on practice, encounters significant limitations in fostering CT. Didactic methods frequently isolate students, thereby restricting peer interaction, the discussion of ambiguous cases, and the immediate feedback that is essential for refining clinical judgment and mitigating bias [6]. Simulations are limited by resource availability, time constraints, and the relevance of scenarios [7] while clinical placements provide inconsistent exposure to a variety of cases and practical opportunities due to environmental complexity and case variability [8]. These pedagogical gaps highlight the need for innovative approaches.

Flipped Learning (FL) and Virtual Reality (VR) have emerged as promising educational solutions. FL reverses traditional instructions: students acquire foundational knowledge prior to class, reserving in-person sessions for practical activities. This model effectively bridges the gaps between theory and practice, enhances student engagement, and fosters problem-solving abilities [9, 10, 11]. VR complements FL by providing immersive, risk-free environments for procedural training, clinical decision-making, and repetitive practice tailored to individual learner needs [12, 13]. Research indicates that VR significantly enhances critical thinking components, such as judgment under pressure [14, 15].

The integration of VR and FL (VR-FL) synergizes flexibility with immersion. Pre-class materials are aligned with preparatory activities, while in-class VR laboratories facilitate active participation [16]. However, VR-FL encounters several challenges: cognitive load resulting from simultaneous processing of theoretical knowledge and multisensory inputs [17] and limited structured collaboration in standard in-class activities, such as discussions and case studies, which hinders interactive clinical reasoning [16].

Collaborative Role-Playing (CRP) addresses these gaps by integrating social learning within simulations. Grounded in contextual cognition theory, CRP enhances communication, teamwork, perspective-taking, and clinical reasoning through team-based problem-solving [18, 19]. Empirical studies have established a connection between CRP and improved knowledge retention, critical thinking, and assessment skills [20, 21], with post-activity debriefing that facilitates the internalization of knowledge [22]. Despite its effectiveness, traditional CRP is constrained by limited scenario diversity and resource availability. No prior study has systematically integrated VR, FL, and CRP to assess their comparative effects on CT. Existing VR-FL models tend to emphasize individual skill practice or group discussions, often overlooking the importance of structured, multi-perspective clinical reasoning during in-class applications. This study uniquely introduces a CRP-based VR-FL approach, which incorporates role assumption (e.g., nurse, patient, family) directly within the in-class phase of VR-FL. This method facilitates real-time negotiation of diverse viewpoints for directly fostering the development of CT and provides a framework for collaborative clinical reasoning that extends beyond mere discussion. This approach aligns with Jeffries' Conceptual Framework [23] for Simulation by integrating preparatory activities (pre-class VR), active participation (CRP), realism (VR immersion) and debriefing. Therefore, this study evaluates the innovative CRP-based VR-FL approach, comparing it with the non-CRP VR-FL. Accordingly, the research questions to be addressed in this study are as follows:

(1) How does CRP-based VR-FL impact student learning achievement compared with non-CRP-based VR-FL?
(2) What are the effects of CRP-based VR-FL on students' critical thinking compared with non-CRP-based VR-FL?
(3) How do nursing students perceive these learning approaches?

Methods

Study design, setting, and participants

This study utilized a mixed-methods quasi-experimental design to examine the effectiveness of the CRP-based VR-FL approach on critical thinking within a core nursing competency, specifically intravenous (IV) infusion skills. The research was conducted at a health vocational college in south China. The intervention and data collection took place over the course of one month.

Two cohorts of nursing students (total $n = 133$) were selected after verifying comparable baseline competencies through specific criteria. For example, evaluations of fundamental knowledge comprehension, assessments of learning capabilities (including logical reasoning, knowledge retention, and practical skills), and reviews of prior course grades were conducted. One cohort was assigned to the control group ($n = 66$), while the other was designated as the experimental group ($n = 67$). To address the absence of a pre-study power analysis, a sensitivity analysis confirmed that the sample size could detect clinically significant effects (Cohen's $d = 0.48$ at $\alpha = 0.05$, power = 80%), which is below the field's minimum important difference ($d = 0.50$) [24]. To minimize confounding variables, both groups received theoretical instructions from the same instructor and utilized the VR-FL teaching model. The experimental variable was manipulated by isolating CRP and non-CRP conditions.

VR-FL training

The experimental group underwent CRP training during IV infusion practice, whereas the control group engaged in traditional individual practice.

Pre-class (1 week): All participants engaged with IV infusion videos and practiced virtually on the V-Care Nursing Virtual Simulation Platform (Fig. 1), which offered personalized feedback tailored to their proficiency.

The theoretical class (90 min) involved both groups observing peer demonstrations on a smart whiteboard, followed by instructor-led discussions addressing various challenges. Students then practiced independently using mobile VR, with guidance from the instructor (Fig. 2).

CRP vs. non-CRP

Figure 3 illustrates a role-playing activity conducted within teams, which included nurses, patients, family members, and healthcare staff in the experimental group. The roles encompassed managing patient anxiety, addressing family inquiries, and facilitating collaborative problem-solving (e.g., challenging punctures), while fostering critical thinking through effective communication and the optimization of strategies. In the control group, the instructor demonstrated the procedure, followed by individual practice, during which guidance was sought exclusively from the instructor.

Assessment

The experimental procedure (Fig. 4) consists of three sequential phases: First, after one week of pre-class learning, all participants completed a pre-test to assess their foundational knowledge and critical thinking skills. Subsequently, both groups participated in a combined session that included a 90-minute theoretical class followed immediately by a 90-minute practical training session. Finally, at the conclusion of the study, participants undertook a post-test that measures knowledge and critical thinking and completed a self-assessment.

Data collection, statistical analysis, and control of confounding variables

Data were collected using three validated instruments: (1) a knowledge test consisting of 20 multiple-choice questions (maximum score: 100 points), developed by expert nursing instructors and exhibiting high reliability (KR20 = 0.83); (2) the Critical Thinking Tendency Questionnaire, a 12-item, 6-point Likert scale instrument validated in nursing contexts to assess attitudes, creativity, and decision-making, demonstrating good internal consistency (Cronbach's $\alpha = 0.79$); and (3) a self-assessment of learning approaches, adapted from Zink and Schmidt's (1998) framework to evaluate self-monitoring, self-evaluation, and the implementation of corrective strategies. All instruments were administered anonymously via an online platform, with participant responses coded as EG (Experimental Group) or CG (Control Group) to ensure confidentiality.

Statistical analyses were conducted using dual approaches. For quantitative data, SPSS 27.0 was utilized to perform independent samples t-tests, complemented by linear mixed-effects models to address the limitations of the quasi-experimental design. These models accounted for variability between groups, individual temporal differences and confounding factors (e.g., prior grades).

For qualitative self-assessment data, thematic analysis was conducted following the framework established by Braun and Clarke [25] in MAXQDA24. Codes were systematically categorized into three core themes (Fig. 5), and inter-coder reliability was rigorously verified using Kappa coefficients to ensure the robustness of the analysis.

To mitigate potential confounding effects, multiple strategies were implemented across both experimental and analytical stages: Prior knowledge was controlled through pre-tests and baseline equivalence verification, ensuring initial group comparability. Variability in group dynamics was minimized by standardizing role-play scenarios with predefined responsibilities (e.g., nurses managing family inquiries) for the experimental cohort. Instructor-related confounders were addressed by employing identical theoretical instructors and content delivery, supplemented by video recordings of practical sessions for consistency audits. Finally, statistical control was achieved by incorporating baseline scores and prior academic performance as covariates in linear mixed-effects models, thereby quantitatively adjusting for residual heterogeneity.

Results

The demographic information of participants

Table 1 presents a comparison of the differences in gender, age, and GPA between the control group ($n = 66$) and the experimental group ($n = 67$). The chi-square test revealed that the gender difference was not statistically significant ($p = 0.67$); similarly, the independent samples t-test indicated that the differences in age ($p = 0.35$) and GPA ($p = 0.57$) were also not statistically significant. In conclusion, there were no statistically significant differences between the two groups in the measured variables.

Fig. 1 Instructional videos and VR simulation of the IV infusion

Fig. 2 Demonstrates and practices IV infusion in the theoretical class

Analysis of IV infusion knowledge test scores

Figure 6 presents a comparison of pre-test and post-test knowledge scores between the experimental and control groups, including error bars representing 95% confidence intervals.

In the pre-test phase, no significant difference was observed between the experimental group (M = 81.79, SD = 13.70) and the control group (M = 79.39, SD = 12.88), t (130) = 1.04, $p = 0.30$, 95% CI [-2.17, 6.96]. However, in the post-test phase, the experimental group (M = 89.85, SD = 13.64) demonstrated significantly higher scores than the control group (M = 81.79, SD = 19.99), t (130) = 2.72, $p = 0.008$, 95% CI [2.18, 13.94], with Cohen's $d = 0.47$ (indicating a medium effect size) supporting practical significance.

Assumption checks confirmed approximate normality through visual inspection of histograms (Fig. 7) and Q-Q plots (Fig. 8). The Levene's test indicated homogeneity of variances (pre-test: F (1, 130) = 0.23, $p = 0.632$; post-test: F (1, 130) = 3.21, $p = 0.075$), validating the use of parametric tests. These findings suggest the intervention effectively improved scores, supporting its efficacy.

Fig. 3 An collaborative role-playing activity in the experimental group

The critical thinking

As illustrated in Table 2, the pre-test results indicated no significant differences between the experimental and control classes across the attitude, creativity, and decision-making dimensions of critical thinking disposition. For the attitude dimension specifically, the experimental group (M = 3.46, SD = 0.49) and control group (M = 3.34, SD = 0.62) yielded a t-value of 1.15 (df = 123, $p = 0.25$), confirming the absence of a significant difference here. Consistent with this pattern, non-significant differences were also observed in the creativity and decision-making dimensions. However, the results of the post-questionnaire indicated that in the decision-making dimension, the difference between the experimental group (M = 4.48, SD = 0.55) and the control group (M = 4.76, SD = 0.69) was significant (t = 2.50, $p < 0.05$), suggesting that the experimental group outperformed the control group in this dimension. In contrast, with respect to the attitudinal dimension, both groups exhibited comparable performance, and the difference did not reach a significant level (t = 1.15, $p > 0.10$). Similarly, no significant difference was observed between the two groups regarding creativity.

The self-assessment of the learning approaches

Table 3 presents self-assessment categorizations. It covers three core themes: mastering IV infusion knowledge/skills, offline training experience, and critical thinking development.

Specifically, we divide participants into the CRP-based VR-FL group and Non-CRP-based VR-FL group, showcasing their views on teaching methods under these themes.

CRP-based VR-FL group

VR-FL boosts learning interest and participation

The VR-FL has significantly enhanced interest and participation in learning. Most students reported that, with the assistance of VR technology, they were able to engage in highly realistic IV infusion operation practice within the V-Care Nursing Virtual Simulation Platform system. Upon entering this highly reproducible virtual ward, students like EG1 below felt as though they were in an actual hospital environment, complete with all the necessary equipment and lifelike virtual patients awaiting their treatment.

Within the VR platform system, I had the opportunity to select infusion instruments, examine medications, and execute a series of procedures such as puncture and immobilization. It truly felt as though I was actively engaged in the treatment process, significantly enhancing my motivation to learn. (EG1)

Furthermore, the implementation of the platform not only increased the enjoyment and interactivity of the learning experience but also transcended the temporal and spatial limitations inherent in traditional classroom instruction. Prior to class, students could preview the IV infusion operation by watching instructional videos, thereby gaining a preliminary understanding of the material they were about to study. EG7 indicated that this pre-practice learning approach enabled students to engage

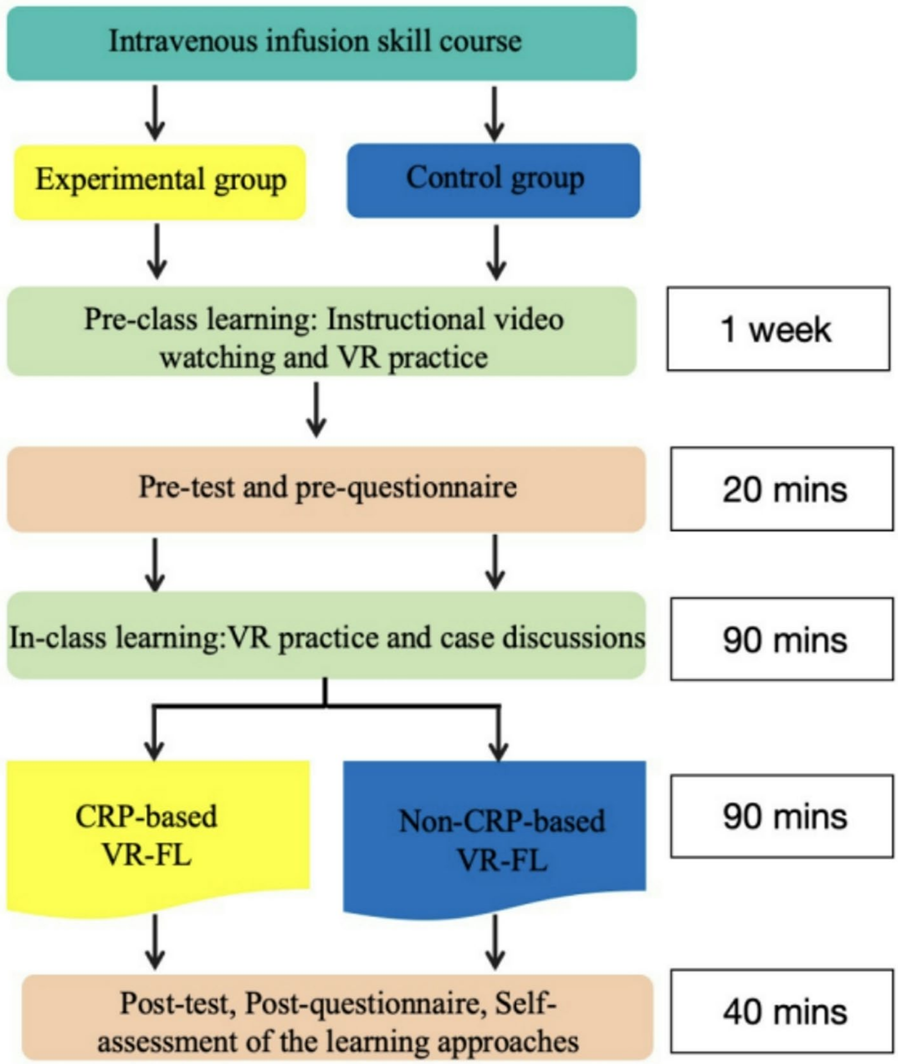

Fig. 4 The experimental procedure

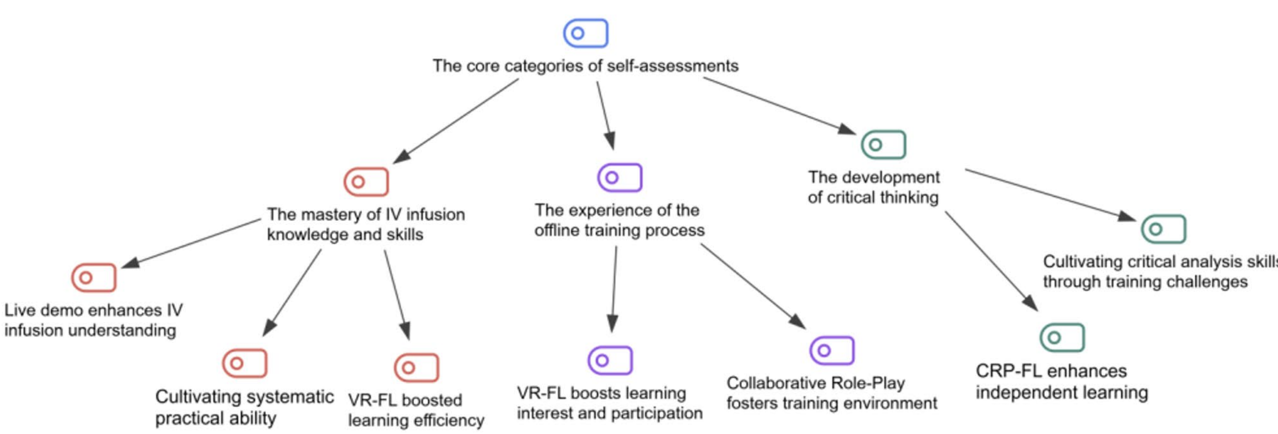

Fig. 5 The core categories of self-assessments

Table 1 Comparison of the participants' demographic information

Groups Variable		Control Group($n=66$)	Experimental Group($n=67$)	p-value
Gender	Female, n(%)	52(78.8%)	55(82.1%)	0.67*
	Male, n(%)	14(21.2%)	12(17.9%)	
Age	Mean ± SD	20.1 ± 1.3	20.3 ± 1.2	0.35**
Prior GPA	Mean ± SD	3.42 ± 0.31	3.39 ± 0.29	0.57**

*Chi-square test **Independent sample t-test

more actively in the educational process, thereby deepening their comprehension and retention of IV infusion knowledge and skills.

Collaborative Role-Play fosters a training environment

The collaborative role-play learning model fostered a conducive offline practical training environment. Students effectively collaborated with their group members to complete the IV infusion task. Some took charge of the operation, while others provided close assistance by handing and holding the instruments and monitoring the patient's reaction. When confronted with an emergency situation, such as a simulated patient experiencing a reaction to an infusion, students were able to respond in an organized manner based on the emergency protocols they had learned in the VR classroom. Participants actively shared their perspectives on the challenges encountered, collaboratively analyzed procedural and interpersonal dynamics, and explored innovative solutions to enhance clinical practice. This integrative approach not only reinforced technical proficiency but also strengthened team cohesion. By fostering a culture of mutual learning and open dialogue, the exercise cultivated a supportive environment in which collective problem-solving and knowledge exchange drove measurable progress. This experience underscores the value of combining immersive technologies with collaborative reflection to achieve both task mastery and professional growth.

When the team member responsible for the operation is administering IV fluids, I will provide close assistance by handing over the instruments and monitoring the patient's reaction. (EG7)

During the discussion session following the completion of the task, we integrated our experiences from the VR scenario with our feelings from the role-playing exercise, actively sharing insights, collaboratively analyzing issues, and exploring potential solutions. (EG9)

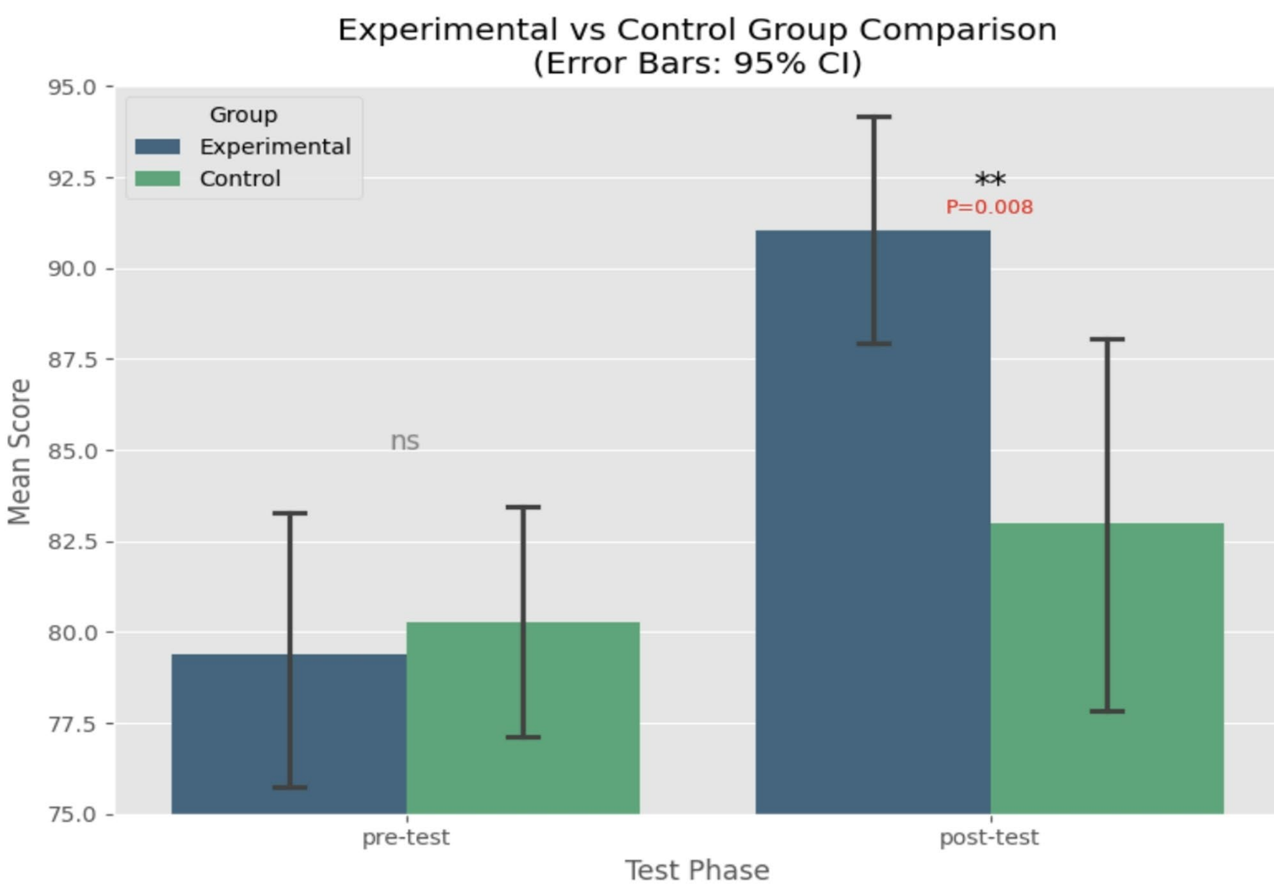

Fig. 6 Experimental Group vs. Control Group Comparison (Error Bars: 95% CI)

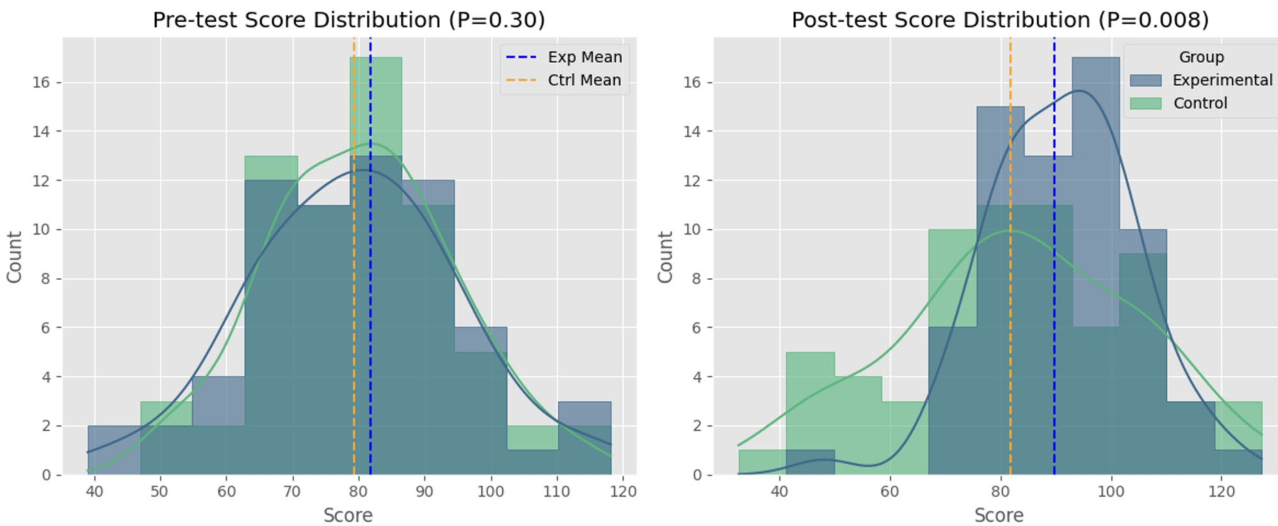

Fig. 7 Histogram with distribution curve and mean marker

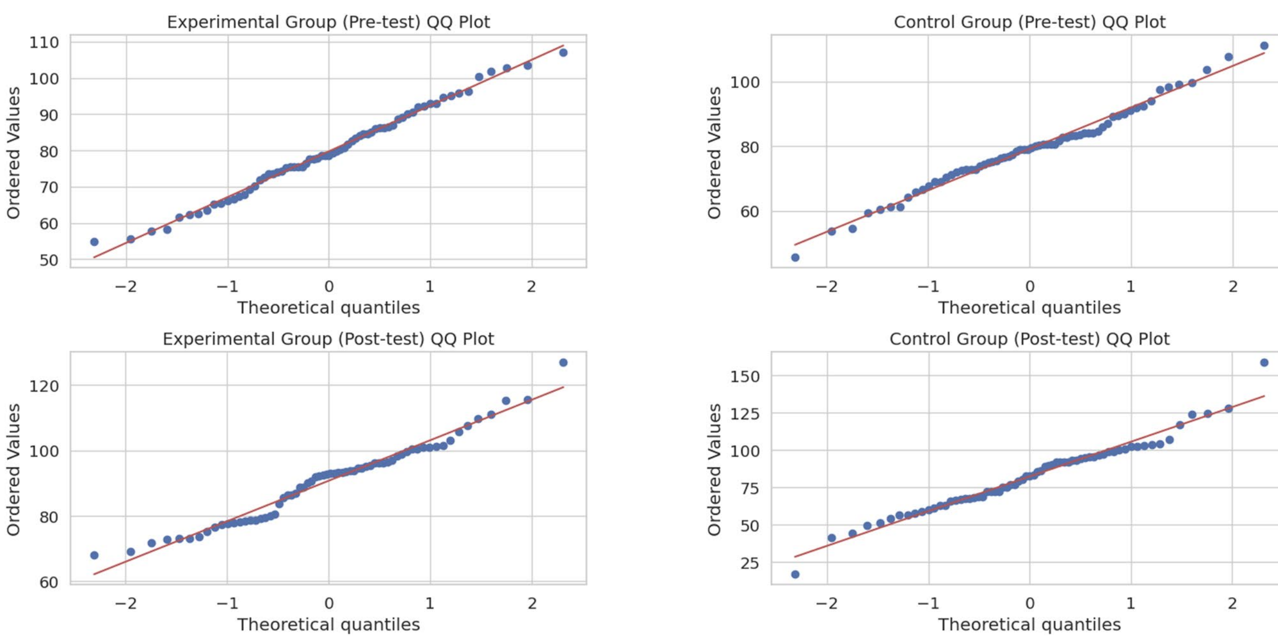

Fig. 8 Pre-test and post-test QQ plot

Through such teamwork, we not only successfully completed the IV infusion task but also cultivated a positive learning atmosphere, where we all learned from one another and made progress together. (EG3)

CRP-FL enhances independent learning

The CRP-FL model further enhanced independent learning. EG5 noted in his self-reflection that when he encountered theoretical confusion while acquiring the knowledge and skills related to IV infusion, he was able to visually comprehend the impact of infusion speed on patients by watching the videos provided by the teacher and the VR simulation of the infusion process for different medications. When EG42 mentioned that he found himself lacking in practical training operations, he reviewed the operational demonstrations in the VR system, compared his own techniques, and identified areas for improvement.

Faced challenges of the learning approaches

However, students also encountered several challenges while utilizing the VR platform. EG5 and EG2 reported negative experiences, such as occasional lag that disrupted usage and the necessity to restart the application after accidentally exiting, which may diminish their motivation to engage with it. Furthermore, while collaborative

Table 2 Independent samples test of critical thinking tendency

Critical Thinking Domain	Group	Time	M	SD	t	*P*-value
Attitude	Experimental	Pre	3.46	0.49	1.15	0.25
	Control	Pre	3.34	0.62		
	Experimental	Post	4.56	0.62	-0.11	0.298
	Control	Post	4.67	0.63		
Creativity	Experimental	Pre	3.62	0.50	0.03	0.97
	Control	Pre	3.62	0.55		
	Experimental	Post	4.70	0.57	-0.12	0.225
	Control	Post	4.82	0.61		
Decision-making	Experimental	Pre	3.49	0.46	1.37	0.17
	Control	Pre	3.63	0.61		
	Experimental	Post	4.48	0.55	-0.28	0.015
	Control	Post	4.76	0.69		

role-playing can enhance teamwork, some students noted that time was wasted due to unskilled operation during practical training, which impacted overall efficiency and may foster negative learning attitudes. In this context, many students desired to develop their clinical resilience through increased VR simulation training and practical exercises. They aspired to leverage the collaborative simulation role-playing feature of VR to explore and navigate the virtual environment, thereby enhancing their skills and self-confidence in managing unexpected situations. Simultaneously, by integrating offline collaborative role-playing, they collaborated with team members to tackle challenges presented in simulated scenarios, thereby strengthening their teamwork and clinical resilience.

Non-CRP-based VR-FL group

VR-FL boosted learning efficiency

The VR flip mode has significantly enhanced the efficiency and effectiveness of learning. Students reported that the video preview provided before class enabled them to gain a systematic understanding of the theoretical knowledge related to IV infusion, as well as a preliminary grasp of the operational procedures and precautions involved. This form of pre-study not only conserves classroom time but also fosters a strong interest in the material to be learned prior to the class. CG2 stated that *"Practicing IV infusion in the VR environment made me feel like a real nurse providing care to patients. This sense of realism has increased my engagement and confidence. I now know the IV infusion procedure thoroughly and am equipped to handle any unexpected situations that may arise."* CG10 remarked that *"The VR Flip Mode afforded me the opportunity to practice repeatedly until I fully mastered each step. This flexibility is unparalleled compared to traditional teaching methods."* Furthermore, CG10 also expressed that *"by practicing with the VR equipment, I uncovered details I had previously overlooked, such as how to better secure the infusion tube and how to minimize discomfort during puncture. Mastering these details is essential for enhancing the quality of care. Additionally, noted that through VR FL, I also learned how to apply my knowledge to address real-world challenges, such as managing the vascular conditions of different patients and selecting the appropriate puncture site."*

Cultivated systematic practical ability

Enhancing one's practical skills is an essential aspect of every learner's journey towards skill acquisition and practical application. In the field of nursing education, particularly concerning hands-on skills such as IV infusion, the enhancement of practical skills is of paramount importance. CG7 has reported that, through the instructor's demonstration, coupled with pre-course previews and VR exercises, the process not only became more systematic and efficient but also significantly ignited their enthusiasm for exploring the unknown and engaging in hands-on practice.

During the pre-course preparation phase, I typically review the video materials provided by the instructor attentively to gain a preliminary understanding of the theoretical knowledge, operational procedures, and precautions related to IV infusion. Throughout this process, I take notes while watching, documenting any concepts I find unclear or areas I believe require further mastery, thereby establishing a solid foundation for subsequent practice and exercises. (CG3)

Live demo enhanced IV infusion understanding

Furthermore, CG4 indicated that the teacher's live demonstration offered her an intuitive and vivid illustration of the learning process. *"During the demonstration, I focused intently on every detail of the teacher's movements, taking note of how he addressed various situations and the precautions he emphasized throughout the procedure."* These observations not only enhanced my understanding of the IV infusion process but also provided me with a more intuitive grasp of the actual operation. Enhancing one's practical skills, this process extends

Table 3 Self-assessment categorizations

Core Categories	Sub-categories	Key words	Examples
Mastering IV infusion knowledge/skills	IV infusion understanding	Vivid illustration; Deepening the comprehension and retention	**CG4:** "The teacher's live demonstration offered me an intuitive and vivid illustration of the learning process." **EG7:** "This pre-practice learning approach enabled to engage more actively in the educational process, thereby deepening the comprehension and retention of IV infusion knowledge and skills."
	Systematic practical ability	Handle unexpected situations; Establishing a solid foundation for practice; Emergency protocols	**CG2:** "Practicing IV infusion in VR made me feel like a real nurse, increasing my engagement and confidence to handle unexpected situations." **CG3:** "During the pre-course preparation, I attentively review videos, take notes on unclear concepts, and document areas that require mastery, thereby establishing a solid foundation for practice." **EG5:** "When confronted with an emergency situation, such as a simulated patient exhibiting a reaction to an infusion, we were able to respond in a systematic manner in accordance with the emergency protocols we had acquired through the VR platform."
	Learning efficiency	Engagement and confidence; Made progress	**CG2:** "Practicing IV infusion in VR made me feel like a real nurse, increasing my engagement and confidence to handle unexpected situations." **EG11:** "Through such collaborative efforts, we can successfully accomplished the IV infusion task and made progress collectively."
Offline training experience	Learning interest and participation	Active engagement; Monotonous and disheartening	**EG1:** "I was actively engaged and significantly enhancing my motivation to learn." **CG7:** "Practicing independently can sometimes feel somewhat monotonous and disheartening."
	Training environment	Sharing insights; Prosthetic for the practice; Fostered a positive learning vibe	**EG7:** "When the team member responsible for the operation is administering IV fluids, I will provide close assistance by handing over the instruments and monitoring the patient's reaction." **CG5:** "Merely utilizing a prosthetic for the practice of intravenous infusion creates a somewhat monotonous training environment." **EG11:** "Teamwork helped us complete IV infusion tasks and fostered a positive learning vibe, where we learned and progressed together."
Critical thinking development	Independent learning	Visual comprehension; Reviews operational demonstrations	**EG5:** "When confused about IV infusion theory, I visually grasped infusion speed's impact via teacher's videos & VR simulations." **CG42:** "Lacking practical training skills, I'll review VR demos, compare techniques, and find areas to improve."
	Critical analysis skills through training challenges	Negative experiences; VR collaborative role - play; Mechanical repetition; No immediate feedback; Cognitive overload	**EG5 & EG2:** "Negative experiences (e.g., lag, needing to restart after accidental exit) may reduce motivation." **Some students:** "Unskilled operation in practical training wastes time, lowers efficiency, and may foster negative attitudes. We expected to use VR collaborative role - play to explore virtual environments and boost skills/confidence for unexpected situations." **Some students:** "When using VR for training, learners get no immediate feedback on operational errors; feedback comes only after the whole process, reducing learning motivation." **CG9:** "Self-practice often led to a mechanical repetition of steps, which impeded the ability to navigate complex situations and resulted in a lack of deep thinking." **EG6 & CG13:** "The cognitive overload and stress resulting from excessive pre-class work."

beyond mere proficiency and mastery of techniques. More importantly, it also cultivates decision-making abilities. CG19 indicates that during the pre-course preparatory phase, she acquired a foundational understanding of the theoretical knowledge and operational procedures related to IV infusion by viewing the video materials. However, this represents only the initial stage of learning, and the true challenge lies in the application of this knowledge in practical settings. The instructor's live demonstration offered her a valuable example of how professionals implement this knowledge in practice, effectively addressing a variety of situations that may arise.

VR exercises, on the other hand, were a key part of honing my decision-making skills. In the VR environment, I immersively simulated a real ward scene and performed countless hands-on IV infusion exercises. In the process, I not only familiarized myself with the operation process, but more importantly, I learned how to make decisions in different situations. (CG8)

After each exercise, I will deeply reflect and summarize my learning process and operation process. I will carefully recall every step I took in the operation and analyze what I did well and what was lacking. (CG12)

Faced challenges of the learning approaches

Regarding the challenges associated with adapting to new technology, some students expressed that when utilizing VR for training, immediate feedback is lacking in the event of an operational error. Feedback is only provided at the conclusion of the entire operational process, which diminished their motivation to learn. In contrast to the collaborative role-playing model employed in the experimental class, students in the control class relied on the traditional methods of teacher demonstration and self-practice. Student CG29 noted that while they enhanced their practical skills, they felt a deficiency in deep thinking and communication. Similarly, CG9 observed that self-practice often led to a mechanical repetition of steps. Furthermore, creativity would be hindered if the tasks are not connected to the students' real-life experiences and learning needs. Consequently, students in the control group expressed a strong desire for increased group discussions. They advocated for the introduction of more real clinical cases to analyze and resolve problems in authentic situations, thereby fostering clinical critical thinking skills. Additionally, many students remarked that although the non-CRP VR-FL model improved their independent learning capabilities, they sometimes experienced heightened stress due to excessive study requirements prior to class. This was particularly true for those who did not complete the pre-class preview, as they struggled to keep pace during class, which could adversely affect their creativity.

Discussion

The integration of CRP within VR-FL significantly enhanced nursing students' academic performance and critical thinking skills. These findings align with broader evidence on simulation-based pedagogy [26]. For example, our results corroborate that role-playing in clinical simulations deepens knowledge application, as demonstrated in studies where students performing physical examinations through role-play showed superior procedural integration and problem-solving compared to traditional methods [27]. The immersive VR environment further amplified this effect by enabling repetitive practice in risk-free scenarios, consistent with research highlighting VR's capacity to improve technical skill retention and clinical decision-making [28].

The marked improvement in critical thinking within our CRP-VR-FL group underscores the synergy between role-play and collaborative learning. By adopting roles (nurse, patient, family), students navigated clinical ambiguities through multi-perspective analysis—an outcome echoing systematic reviews confirming that role-play cultivates clinical judgment and adaptive reasoning [29]. Notably, teamwork dynamics in our intervention mirrored findings from Galindo [30] where role-play reduced resistance to student-centered learning and enhanced peer communication. This suggests CRP-VR-FL not only builds technical proficiency but also addresses core competencies in interprofessional collaboration.

Contrary to performance metrics, learning attitudes showed no significant intergroup difference. Both cohorts perceived VR as engaging and interactive, likely reflecting the inherent appeal of immersive technology itself rather than pedagogical design—a phenomenon noted in UbiSim's survey, where 84% of nursing students rated VR simulations equal or superior to mannequin-based training [31]. Similarly, creativity gains were marginal. While CRP-VR-FL provided collaborative problem-solving opportunities, creativity in clinical contexts demands longitudinal development. This aligns with Bender-Salazar's experiential learning theory [32], wherein iterative cycles of reflection and application (beyond a single intervention) are essential for innovative thinking. Short-term interventions, as in our study, may insufficiently disrupt entrenched cognitive patterns to foster measurable creativity shifts.

The study faced limitations related to time and resources, which resulted in the collection of a relatively small number of samples. Although the sample size was statistically representative, a larger sample could have provided more comprehensive and nuanced analytical outcomes. Additionally, the research primarily focused on a specific area of nursing education, thereby excluding other relevant domains. Furthermore, the duration of the experimental phase was restricted, as the teaching intervention was implemented over a single course, which may not adequately capture the long-term effects of the CRP-based VR-FL pedagogy on students' learning outcomes. Although the content selection and activity format have been certified by experts, they have not been piloted in a small sample, which is one of the limitations of the study.

Conclusion

This research investigates the effectiveness of integrating the CRP-based VR-FL approach in nursing education through a comparative experiment. The experimental group utilized the hybrid learning methods of CRP-based VR-FL, while the control group employed traditional VR-FL. The results indicated that the experimental group significantly outperformed the control group in terms of IV infusion knowledge acquisition, critical thinking (particularly decision-making ability), as well as learning interest, classroom participation, teamwork and independent learning skills. Research has demonstrated that the deep integration of CRP-based VR-FL approach can effectively enhance the multidimensional training in nursing education. This study demonstrates that educators should actively explore and integrate a variety of teaching methods to optimize instructional effectiveness. Furthermore, instructors can leverage modern technologies, such as VR, to create more immersive and interactive learning environments for students [33], thereby enhancing both the learning experience and its effectiveness. The results of the self-assessment indicated that the learning approaches significantly increased students' interest in learning, engagement, teamwork, and independent study. This underscores the importance of encouraging students to engage in self-assessment throughout the teaching and learning process, allowing them to recognize their own learning status through reflection and feedback, and subsequently adjust their learning strategies to improve their effectiveness. Given the successful implementation of this study in nursing education, educators may consider extending this pedagogical approach, which integrates virtual FL and role-playing, to other educational fields to explore its applicability and effectiveness across various disciplinary contexts.

Future research should aim to collect a larger sample size to improve the generalization and robustness of the findings. Moreover, expanding the research to include a wider array of nursing courses and clinical scenarios would help validate the applicability of the CRP-based VR-FL approach. Investigating ways to optimize the interactivity and personalized features of the VR platform to better meet the diverse learning needs of students would also be advantageous. Lastly, conducting longitudinal studies to track students' performance in clinical practice would provide valuable insights into the impact of this learning approach on their long-term career development, representing a significant direction for future research.

Abbreviations

CT	Critical thinking
VR	Virtual Reality
FL	Flipped Learning
CRP-based VR-FL	Collaborative Role-Playing-Based Virtual Reality Flipped Learning
IV	intravenous

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12912-025-03709-2.

Supplementary Material 1

Supplementary Material 2

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Author contributions

Yongqiao Li and Yuting Chen designed and implemented the study on the impact of VR role-playing in nursing education. Junjie Gavin Wu, as the corresponding author, was responsible for the overall planning, design, execution, and manuscript writing of the study, particularly the in-depth exploration of the application of VR role-playing combined with a flipped classroom in nursing education. Danyang Zhang participated in the design and implementation of the study, provided expertise in the field of nursing education, and analyzed and discussed the research results. Yuting Chen participated in the data collection and analysis of the study, especially providing professional support in the processing of student self-assessment data and helping to interpret the impact of VR role-playing on students' learning experience. All authors reviewed the manuscript.

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Data availability

The datasets generated and/or analyzed during the current study are not publicly available due to the necessity to ensure participant confidentiality policies and laws of the country but are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

The present study was conducted by the principles of the revised Declaration of Helsinki, a statement of ethical principles that directs physicians and other participants in medical research involving human subjects. All participants signed the informed consent to participate in the study. All personal information remain confidential, and they were free to withdraw at any stage of the study. The participants were assured of the anonymity and confidentiality of their information. Moreover, the local ethics committee of the School of Guangdong Maoming Health Vocational College approved the study.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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