

Effects of virtual reality, feedback-based virtual reality, and interactive lecture–based ESI triage training on triage accuracy and nursing students' satisfaction: a quasi-experimental study

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Abstract

Background Accurate triage is essential for efficient emergency care; however, little is known about the comparative effectiveness of interactive lecture (IL), virtual reality (VR), and feedback-based virtual reality (FVR) for Emergency Severity Index (ESI) triage training among nursing students.

Aim This study investigated the effects of interactive lecture (IL), VR, and FVR on the precision of triage assessments and on nursing students' satisfaction with the Emergency Severity Index (ESI)..

Methods A quasi-experimental pretest–posttest design with three arms was conducted among sixth-semester nursing students ($n=64$) at Shahid Beheshti University of Medical Sciences in Tehran, Iran. Participants were assigned non-randomly, according to their existing course sections and the scheduling of the training sessions, to IL ($n=22$), VR ($n=22$), or FVR ($n=20$). Triage accuracy was evaluated using a 10-item scenario-based assessment administered before the intervention, immediately after its completion, and one week later. Satisfaction was measured utilizing a validated 18-item questionnaire. Data analysis was performed using repeated-measures ANCOVA and one-way ANOVA, with a significance level set at $p<0.05$.

Results Among 64 nursing students, baseline demographic characteristics and GPA were comparable across groups; baseline triage accuracy was highest in the FVR group, and the between-group difference approached significance ($p=0.055$), so all comparisons were adjusted for baseline accuracy. Immediately after the intervention, mean triage accuracy was highest in the FVR group, followed by the VR and IL groups; however, the between-group difference was not statistically significant ($p=0.328$). The overall main effect of time was not statistically significant ($p=0.391$). At the one-week follow-up, accuracy declined in the VR and FVR groups but continued to improve in the IL group, resulting in a significant time $\times$ group interaction ($p=0.028$), suggesting different learning trajectories across instructional methods. Satisfaction was high and comparable across all groups ($p=0.63$), indicating similar acceptability.

Conclusion All three instructional methods were favorably regarded by students, and post-intervention triage accuracy did not differ significantly between them at either assessment point. The overall main effect of time was not statistically significant; however, the significant time $\times$ group interaction indicates that accuracy followed

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different trajectories across methods, with continued improvement in the IL group at one week. These findings do not establish the superiority of any single method. VR may serve as a complement to instructor-led teaching rather than a replacement for structured discussion and guided reasoning, and larger studies with longer follow-up are required to confirm these patterns.

Trial registration Not applicable.

Keywords Virtual reality · Interactive lecture · Emergency severity index · Nursing students · Triage accuracy · Satisfaction

Introduction

Triage aims to provide optimal care to the most significant number of patients by stratifying individuals according to the urgency of their medical requirements. The term derives from the French word “*trier*,” historically used in the 15th century to categorize goods based on price and quality [1]. Contemporary triage methodologies in civilian emergency departments were initially defined by Weinerman et al. in 1964 [2].

Accurate triage is essential for optimal resource allocation and improved patient outcomes; however, research indicates that only 59% of triage assessments are precise [3, 4]. Its importance is especially pronounced in high-volume emergency departments [5]. Internationally, various systems are used, including the Australian Triage Scale, the Manchester Triage System, and the Emergency Severity Index (ESI), which is used in the United States and Iran [3, 5].

The ESI, widely used in hospital triage protocols, classifies patients into five categories based on acuity and resource requirements. Levels 1 and 2 are predominantly determined by the severity of the patient’s condition. In contrast, levels 3 through 5 depend on the quantity of resources required, such as laboratory tests, intravenous fluids, or consultations [4, 6, 7]. The most recent revision (ESI v5, 2023) includes age-adjusted vital signs to enhance differentiation between levels 2 and 3 [4, 6, 7]. The ESI has demonstrated significant advantages, including the rapid identification of high-risk patients, improved staff and patient satisfaction, optimal resource utilization, and the development of a standardized communication framework [3, 4, 6].

In view of the escalating demands posed by a growing population and the insufficient expansion of emergency services, it is crucial to implement effective triage training to reduce delays, errors, and adverse outcomes [5, 8, 9]. Although traditional lectures are frequently utilized, they often lack active student engagement and may be less effective in teaching triage skills [10–12]. Enhanced interactive lectures, involving discussions and case analyses, promote active, student-centered learning [10, 11, 13, 14]. Simulation-based approaches provide safe environments for skill development; however, the use of traditional mannequins can be costly, occupy considerable space, and may not accurately replicate real clinical scenarios [15–17].

Emerging technologies such as virtual reality (VR) provide immersive, computer-generated three-dimensional environments that enable users to experience and interact with simulated real-world settings through head-mounted displays and motion tracking, creating a sense of presence within the virtual environment [18]. These environments facilitate safe, flexible, and performance-tracked practice [12, 19–23]. In the present study, feedback-based virtual reality (FVR) refers to the same immersive VR scenarios used in the VR group, supplemented by a structured, facilitator-guided debriefing after each scenario. During this debriefing, learners stated their assigned triage level and rationale, received corrective feedback, and discussed the reasoning underlying the expected decision. This operationalization is consistent with evidence emphasizing the role of formative feedback and structured debriefing in technology-enhanced simulation learning [20, 22]. Research indicates that VR enhances engagement and satisfaction; however, studies report mixed results on triage performance compared with lectures or live simulations [12, 24–26].

A three-way comparison of IL, VR, and FVR is educationally important beyond the introduction of new technology, as these approaches differ in instructional guidance, learner autonomy, environmental realism,

interactivity, feedback, cognitive demands, and resource requirements. Interactive lectures allow for immediate clarification and discussion, whereas VR provides immersive, realistic clinical experiences, and FVR adds structured feedback that may facilitate error correction and skill refinement [27]. Therefore, comparing these modalities can help determine whether differences in triage learning outcomes are related primarily to technological immersion, instructional guidance, feedback mechanisms, or the way clinical information is presented and processed. Such evidence can support evidence-based curriculum development and assist nursing educators in selecting educational approaches that are both effective and feasible [27].

This study is also guided by Cognitive Load Theory (CLT) and Multimedia Learning Theory. CLT suggests that working memory has limited capacity and that effective instructional design should minimize unnecessary cognitive demands while supporting meaningful learning [28, 29]. This perspective is particularly relevant to triage education, where students must rapidly integrate multiple clinical variables and make complex prioritization decisions [29]. Multimedia Learning Theory further proposes that learners construct knowledge by integrating verbal and visual information with prior knowledge [30]. Accordingly, VR and FVR may enhance learning by providing realistic visual representations and interactive experiences; however, their effectiveness depends on appropriate instructional design rather than immersion alone.

Considering the paramount importance of triage in optimizing resource allocation, reducing treatment delays, and improving patient outcomes, it is imperative to ensure that training is both effective and dependable. Evidence regarding the implementation and effectiveness of innovative educational methodologies, including VR, in triage training remains inconsistent. Despite the growing use of VR in nursing education, direct comparative evidence on the effectiveness of interactive lecture (IL), VR, and feedback-based virtual reality (FVR) for Emergency Severity Index (ESI) triage training remains limited. Furthermore, with recent modifications to the ESI algorithm, including the integration of age-adjusted vital signs, evaluating the effectiveness of these educational approaches in accordance with updated guidelines has become increasingly important. Therefore, this study aimed to compare IL, VR, and FVR in terms of triage-level estimation accuracy and nursing students' satisfaction.

Method

Design and setting

This study employed a quasi-experimental pretest–posttest design with three groups and was documented in accordance with the TREND (Transparent Reporting of Evaluations with Nonrandomized Designs) guidelines (Supplementary Material 1) [31]. Participants were not randomly allocated to the study groups: group assignment followed existing course sections and the training session schedule, and no random allocation sequence was generated. The study is therefore reported as a nonrandomized evaluation, consistent with the TREND statement. This research was conducted at the School of Nursing and Midwifery, Shahid Beheshti University of Medical Sciences, Tehran, Iran.

Participants

The study involved sixth-semester nursing students from the School of Nursing and Midwifery at Shahid Beheshti University of Medical Sciences who met the inclusion criteria and provided informed consent. Participants were required to have completed the preceding five semesters, to be enrolled in the “Emergency Nursing in Crises and Disasters” course for the first time, and to demonstrate proficiency in operating VR equipment. Students were excluded if they participated in any other educational program during the study, withdrew from either the research or the nursing program, expressed unwillingness to continue, were employed in the emergency department or triage unit during the study, or submitted incomplete questionnaires.

Sample size

The required sample size was calculated using GPower software (version 3.1). Because the primary objective was to examine the time $\times$ group interaction, an F test with the repeated-measures between-within interaction option was used. Assuming three groups and three measurement points, an effect size of $f=0.379$ was used, denoting a moderate-to-large effect [32]. The significance level was set at $\alpha=0.05$, and the statistical power at 0.80. The correlation among repeated measurements was presumed to be 0.5, and the nonsphericity correction factor was set to 1. Based on these assumptions, the minimum required sample size was estimated at 54 participants (18 per group). To account for an anticipated attrition rate of 20%, the final sample size was adjusted to 66 participants, with 22 per group. Ultimately, 64 participants were included in the final analysis because two participants in the FVR group were absent on the day of the intervention and final assessment and did not complete the required evaluations.

Intervention

This quasi-experimental study evaluated the accuracy of triage level estimation (assessed before, immediately after, and one week following the intervention) and participant satisfaction with the pedagogical approach (assessed before and after the intervention) across three instructional modalities: (1) VR, (2) FVR, and (3) IL. A list of all sixth-semester nursing students was obtained from the School of Nursing and Midwifery. Eligible students who agreed to participate were enrolled in the study. Following enrollment, participants were assigned to one of three educational groups: interactive lecture (IL), virtual reality (VR), or feedback-based virtual reality (FVR). Because the intervention had to be delivered within the existing timetable of the “Emergency Nursing in Crises and Disasters” course, assignment was determined by the students’ existing course sections and the scheduled training sessions rather than by a random allocation sequence. Assignment continued until the intended number of participants per group was reached, so that group sizes remained approximately balanced.

Content development

Content for all three modalities was obtained from the finalized ESI Triage guideline. For the IL, instructional slides were meticulously created in accordance with the final guideline and subsequently reviewed and approved by a specialized committee. Regarding the VR interventions, a multidisciplinary expert committee, including research team members, medical education specialists, emergency medicine clinicians, and e-learning professionals, drafted multiple triage scenarios that were iteratively reviewed and refined until consensus was reached. Scripts illustrating triage scenes featuring simulated patients and a triage nurse in a realistic emergency triage environment (including ambient noise and makeup) were prepared. Filming was conducted using a 360° camera with real actors in a triage setting; a VR engineer subsequently handled VR editing and integration. The specialist committee further reviewed the preliminary VR content to ensure fidelity to learning objectives and realism.

Participant recruitment

Following approval from the Institutional Review Board at Shahid Beheshti University of Medical Sciences and authorization from the university’s Research Deputy, the researcher engaged the School of Nursing and Midwifery to undertake participant recruitment. A list of all eligible sixth-semester nursing students was obtained from the School of Nursing and Midwifery. Students who met the eligibility criteria and provided written informed consent were enrolled in the study. Recruitment commenced on 13 August 2024, one week after ethical approval was granted, and continued for two months and ten days until 24 October 2024, during which eligible students were enrolled and the training sessions were delivered. Because triage accuracy was reassessed one week after each session, the final follow-up assessment was completed on 31 October 2024. After enrollment, each participant

was assigned a unique identification code for data-management purposes. Group assignment was non-random. Participants were allocated to one of the three intervention groups (IL, VR, or FVR) based on their existing course sections and scheduled training sessions, and assignments continued until the intended number of participants per group was reached. No random allocation sequence was generated, and no allocation concealment procedure was applied. Given the nature of the intervention and its educational component, we could not blind the interventionist or participants; therefore, we ensured that the outcome assessors and the analyst were blinded.

Interactive lecture (IL)

All participants in the interactive lecture group initially completed the demographic form. Subsequently, a pretest comprising ten scenario-based items evaluating triage estimation accuracy was administered. Participants received a concise overview of the ESI triage using a standardized flowchart. The instructional session lasted two hours and employed an interactive format, incorporating case presentations, guided reasoning, and facilitated discussions. During case analyses, the instructor promoted dialogue among students and between students and the instructor. Students were responsible for determining triage levels for the scenarios presented and justifying their decisions. The instructor provided step-by-step guidance and corrective prompts whenever participants diverged from correct reasoning.

Virtual reality (VR)

Participants assigned to the VR arms also completed the demographic form and the identical 10-item pretest. Students were organized into small groups of four for the VR sessions. Each group received a brief orientation to the ESI Triage utilizing the standardized flowchart and a short prerecorded conventional video. Subsequently, students viewed the VR scenarios using head-mounted displays and headphones, observing each from a first-person perspective that reflected a clinician operating in that environment. Participants in both VR groups were permitted to repeat scenarios within the session and could view each video up to two times. Faculty facilitators were available to provide technical support and guidance.

Feedback-based virtual reality (FVR)

In the FVR group, an additional structured debriefing session was conducted after each scenario. Students engaged in approximately five minutes of discussion, during which they reported the triage level they had assigned and the rationale for their decision; the facilitator then provided corrective feedback and elaboration based on the learners' responses. The debriefing followed a post-event, facilitator-guided format consistent with established descriptions of healthcare simulation debriefing. Conversely, the VR group received identical exposure to scenarios and facilitator support but without the structured scenario-by-scenario feedback debrief.

Post-intervention follow-up

Immediately following the instructional session, all participants across the three groups completed a posttest comprising 10 scenario-based items, designed from real-world situations and calibrated for difficulty. Participants were required to specify the triage level and provide justifications for their decisions. The same testing procedure was administered again one week later, using a comparable set of items, to evaluate retention of triage estimation accuracy. Additionally, following the intervention, all students completed a satisfaction questionnaire to assess their satisfaction with the instructional method. Each test was scored according to established criteria, producing an accuracy score for each individual.

Data collection tools

Data were collected using three instruments: (1) the Amanat et al. satisfaction with teaching method questionnaire (2), a set of scenario-based items to assess triage estimation accuracy, and (3) a researcher-developed demographic questionnaire.

Satisfaction with teaching method questionnaire

Participant satisfaction was assessed using the questionnaire developed by Amanat et al. (2009) [33]. The instrument comprises 18 items rated on a 5-point Likert scale (1 = strongly disagree; 2 = disagree; 3 = neutral; 4 = agree; 5 = strongly agree), producing total scores ranging from 18 to 90. In the original validation research, content validity was established by eight faculty members, and internal consistency was evidenced by a Cronbach's alpha coefficient of 0.89 [33]. In the current study, the content validity of the questionnaire was reviewed by ten faculty members from the School of Nursing, and ten nursing students assessed its face validity. Internal consistency within this sample was high, with a Cronbach's alpha coefficient of 0.94.

Scenario-based triage test

The accuracy of triage estimation was evaluated using thirty scenario-based items that accurately emulate real clinical situations. The research team developed these scenarios and subsequently had them reviewed and approved by three triage nurses and two emergency medicine physicians to ensure clinical authenticity and content validity. The thirty items were systematically divided into three equivalent forms, each containing ten items, designated for pretest, immediate posttest, and one-week follow-up, thereby maintaining balanced difficulty across the sets. Each item comprises a four-option multiple-choice question scored dichotomously (1 = correct, 0 = incorrect), and each ten-item test yields a score ranging from 0 to 10.

Item analysis

The quality of items was assessed utilizing difficulty and discrimination indices. For each test, the upper 27% and lower 27% of examinees, ranked by total test score, were identified, and their response patterns were used to compute indices using standard classical test theory methods. The difficulty index, ranging from 0 to 100, was interpreted as follows: values between 30 and 70 denote acceptable item difficulty; values of 29 or below signify excessively difficult items, while values of 71 or above indicate elementary items. In such cases, items were considered for revision or elimination. The discrimination index, spanning from -100 to +100, reflects the extent to which an item distinguishes between high- and low-performing examinees; items exhibiting zero or negative discrimination were deemed non-discriminative and were considered for exclusion.

Demographic questionnaire

A researcher-designed demographic and academic questionnaire collected participants' characteristics, including sex, age, marital status, and mean grade point average (GPA) over the previous five semesters.

All instruments were administered under standardized conditions at identical time points across groups (demographic form and pretest before the intervention; posttest immediately after the intervention; follow-up test one week post-intervention). Scoring procedures and item analyses were pre-established and applied uniformly to ensure the comparability of outcome measures across study arms.

Data analysis

Data were analyzed using IBM SPSS Statistics (version 20). A two-tailed significance level of $\alpha=0.05$ was considered statistically significant for all analyses. Continuous variables are presented as means $\pm$ standard deviations (SD), whereas categorical variables are presented as frequencies and percentages.

Baseline demographic and academic characteristics were summarized using descriptive statistics. Comparisons among the three instructional groups were conducted using one-way analysis of variance (ANOVA) for continuous variables and chi-square (χ^2) tests or Fisher's exact tests, as appropriate, for categorical variables.

Before conducting inferential analyses, the normality of continuous variables was assessed using the Shapiro–Wilk test, and the homogeneity of variances was evaluated using Levene's test. For repeated-measures analyses, the assumption of sphericity was examined using Mauchly's test. When the assumption of sphericity was violated, Greenhouse–Geisser or Huynh–Feldt corrections were applied.

Changes in triage-level estimation accuracy over time and differences among the three instructional groups were analyzed using a mixed-design repeated-measures ANCOVA, with time as the within-subjects factor, instructional group (FVR, VR, and IL) as the between-subjects factor, and baseline (pre-test) accuracy scores as a covariate. Effect sizes were reported as partial eta squared (partial η^2). Post-intervention nursing student satisfaction scores among the three instructional modalities were compared using one-way ANOVA, with Scheffé post-hoc tests for pairwise between-group comparisons. Mean differences (MD) were also reported for the statistical comparisons.

Ethical considerations

This study was conducted in accordance with ethical principles and the Declaration of Helsinki. Ethical approval was obtained from the Ethics Committee of Shahid Beheshti University of Medical Sciences (IR.SBMU.PHARMACY.REC.1403.107), and the university's Research Deputy granted permission to access participants. Eligible students were fully informed about the study objectives, procedures, and potential risks and benefits, and written and verbal informed consent was obtained. Participation was voluntary, and participants could withdraw at any time without consequence. Confidentiality and anonymity were strictly maintained, and all data were securely stored to ensure privacy and research integrity.

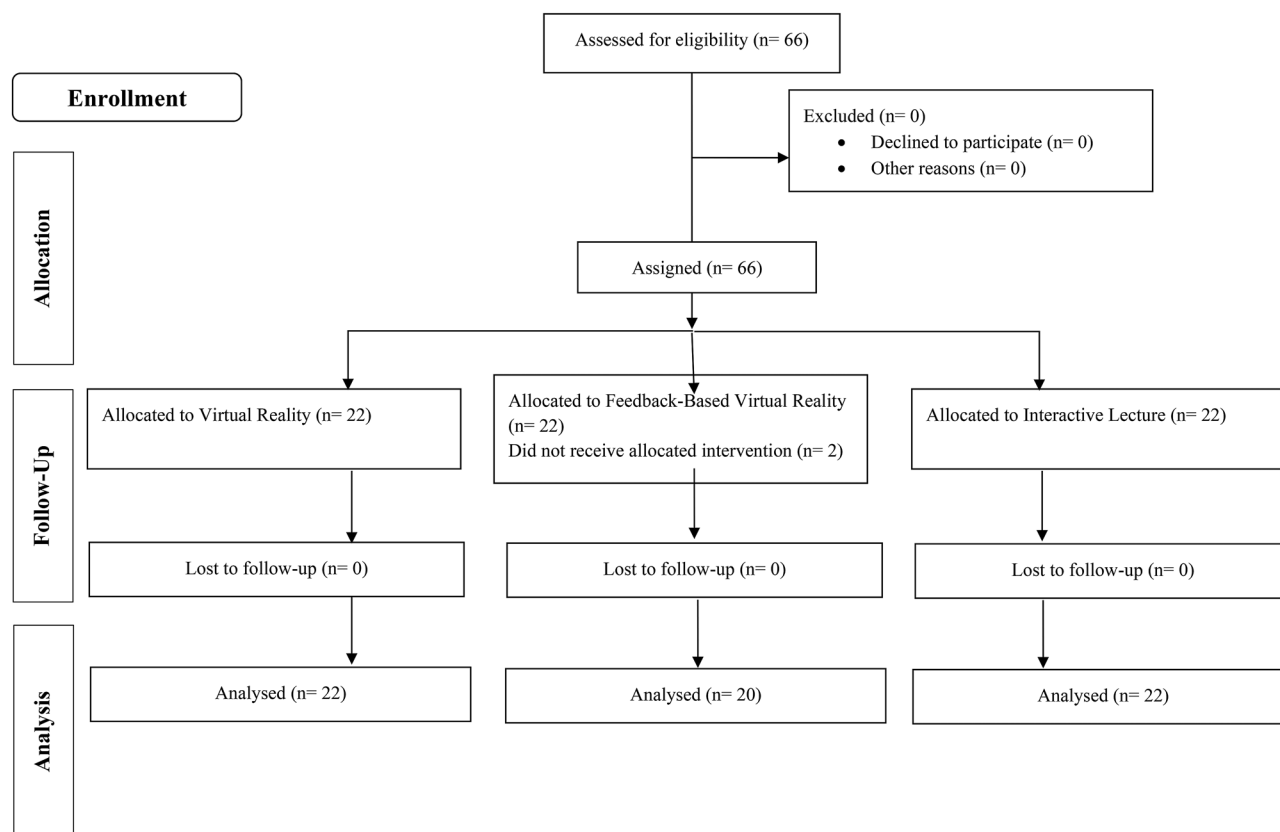
Results

Participant characteristics

A total of 66 sixth-semester nursing students were initially evaluated for eligibility and assigned to the three instructional groups. Two participants allocated to the FVR group did not receive the allocated intervention, as they were absent on the day of the intervention and of the final assessment; no participant was lost to follow-up thereafter. The final analytical sample therefore comprised 64 students: FVR ($n=20$), VR ($n=22$), and IL ($n=22$) (Fig. 1).

Overall, 34 participants (53.1%) were female and 30 (46.9%) were male. The distribution of sex did not differ significantly among the three groups ($p=0.45$). Most participants were single (93.7%), and marital status was comparable across groups, with no statistically significant differences observed ($p=1.00$).

The mean age of participants was 23.53 ± 3.06 years, and the mean GPA was 17.00 ± 0.89 . No statistically significant differences were observed among the three groups with respect to age or GPA ($p=0.55$ and 0.49 , respectively). Baseline demographic and academic characteristics are summarized in Table 1.

**Fig. 1** Study flowchart**Table 1** Baseline demographic and academic characteristics

Education Methods		FVR	VR	IL	Total	p-value
Variable		Mean±SD, n	Mean±SD, n	Mean±SD, n	Mean±SD, n (%)	
Sex	Female	9 (45.0)	11 (50.0)	14 (63.6)	34 (53.1)	0.45 ^a
	Male	11 (55.0)	11 (50.0)	8 (36.4)	30 (46.9)	
	Total	20 (100)	22 (100)	22 (100)	64 (100)	
Marital Status	Married	1 (5.0)	2 (9.1)	1 (4.5)	4 (6.3)	1.00 ^b
	Single	19 (95.0)	20 (90.9)	21 (95.5)	60 (93.7)	
	Total	20 (100)	22 (100)	22 (100)	64 (100)	
Age		24.15±4.91	23.32±2.15	23.18±1.05	23.53±3.06	0.55 ^c
					64 (100)	
Students' Grade Point Average		16.83±1.03	16.97±0.85	17.17±0.82	17.00±0.89	0.49 ^c
					64 (100)	

FVR: Feedback-based virtual reality; VR: Virtual reality; IL: Interactive lecture. ^a Chi-square test. ^b Fisher's exact test. ^c One-way ANOVA

Triage level estimation accuracy

Before the intervention, the mean accuracy scores were 4.10 ± 1.29 in the FVR group, 3.18 ± 1.26 in the VR group, and 3.32 ± 1.32 in the IL group. The between-group difference at baseline did not reach statistical significance, although it approached the conventional threshold ($F(2, 61) = 3.04$, $p = 0.055$, $\eta^2 = 0.091$), with the FVR group scoring highest before training. Baseline accuracy was therefore entered as a covariate in all subsequent between-group comparisons. Immediately after the intervention, the mean accuracy scores were 5.60 ± 1.43 in the

FVR group, 5.23 ± 1.51 in the VR group, and 4.91 ± 1.41 in the IL group. Between-group comparison at this time point showed no statistically significant difference among the three educational methods ($p=0.328$, $\eta^2=0.036$).

One week after the intervention, the mean accuracy scores were 5.00 ± 1.75 for FVR, 4.14 ± 1.81 for VR, and 5.41 ± 1.99 for IL. The between-group comparison at one week also did not reach statistical significance, although a larger effect size was observed compared with the immediate post-intervention assessment ($p=0.085$, $\eta^2=0.079$).

Repeated-measures ANCOVA demonstrated no significant main effect of time on the accuracy of triage level estimation ($p=0.391$, $\eta^2=0.012$). However, a statistically significant time $\times$ group interaction was observed ($p=0.028$, $\eta^2=0.114$), indicating that changes in accuracy over time differed significantly across the three educational methods. Table 2 shows the effects of time and educational method on the accuracy of triage level estimation.

The estimated marginal means indicate that the accuracy of triage level estimation varied over time in accordance with the instructional method employed, exhibiting distinct patterns among different groups. In the FVR and VR cohorts, accuracy increased from baseline to immediately post-intervention, attaining peak levels at this juncture, followed by a decline at the one-week follow-up. Descriptively, this pattern is consistent with virtual reality-based interventions producing more rapid short-term gains in triage accuracy, with the largest values observed immediately after training and lower values at one week. Conversely, the Lecture group demonstrated a consistent, gradual increase in accuracy across all three time points, culminating in its highest level at the one-week follow-up. This pattern indicates a delayed but more sustained learning effect attributable to traditional lecture-based instruction. Overall, these findings suggest that the effect of educational method on triage accuracy may be time-dependent. However, these trajectories are descriptive comparisons of estimated marginal means: the main effect of time was not statistically significant and no between-group comparison reached statistical significance at either post-intervention time point. They should therefore be regarded as exploratory and interpreted with caution (Fig. 2).

Nursing Student satisfaction

Participant satisfaction with the instructional method was high across all study arms. A one-way ANOVA revealed no statistically significant differences in post-intervention satisfaction scores among the three educational methods ($p=0.63$), indicating comparable acceptability of FVR, VR, and IL. Detailed descriptive statistics and between-group comparisons are presented in Table 3. Specifically, students in the FVR group reported slightly higher satisfaction scores than those in the VR group ($MD=1.36$) and slightly lower scores compared with the IL group ($MD=-2.05$); however, these differences were not statistically significant. Similarly, VR participants had marginally lower satisfaction scores than IL participants ($MD=-3.41$), but this difference was also not statistically significant (Table 4).

Table 2 Effects of time and education method on the accuracy of triage level estimation

Variables	Groups	Before the intervention Mean $\pm$ SD	Immediately after the intervention Mean $\pm$ SD	1 week after the intervention Mean $\pm$ SD	Between Group Comparison (Immediately After)	Between Group Comparison (1 Week After)	Repeated measurement ANCOVA, overall (p-value, η^2)	
							Time	Time $\times$ Group
Accuracy of Triage Level Estimation (0 to 10)	FVR	4.10 $\pm$ 1.29	5.60 $\pm$ 1.43	5.00 $\pm$ 1.75	$p=0.328$, $\eta^2=0.036$	$p=0.085$, $\eta^2=0.079$	$p=0.391$, $\eta^2=0.012$	$p=0.028$, $\eta^2=0.114$
	VR	3.18 $\pm$ 1.26	5.23 $\pm$ 1.51	4.14 $\pm$ 1.81				
	IL	3.32 $\pm$ 1.32	4.91 $\pm$ 1.41	5.41 $\pm$ 1.99				

FVR: Feedback-based virtual reality; VR: Virtual reality; IL: Interactive lecture. All p -values are adjusted for pre-intervention scores. Baseline (pre-intervention) between-group comparison: $F(2, 61)=3.04$, $p=0.055$ (one-way ANOVA)

Fig. 2 Changes in the mean of accuracy of triage estimations per groups through three time points (1=before, 2=immediately after, 3=one-week after the intervention). Values are estimated marginal means adjusted for pre-intervention scores. FVR: feedback-based virtual reality; VR: virtual reality; IL: interactive lecture

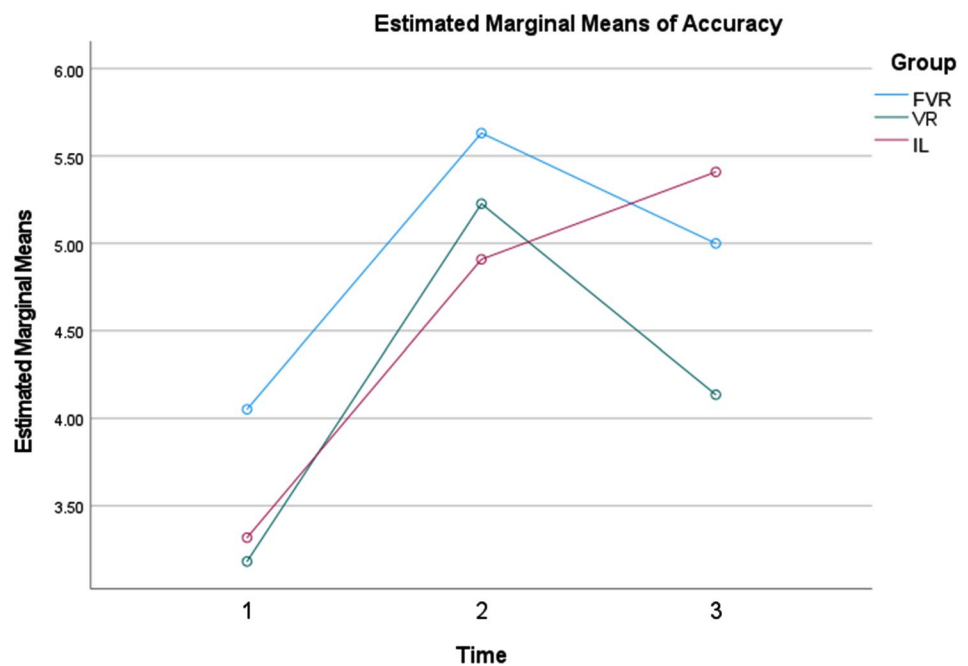


Table 3 Satisfaction scores across education methods

Variable	Education methods	n	Mean ± SD	p-value
Satisfaction	VR	22	77.14 ± 12.12	0.63 ^a
	FVR	20	78.50 ± 12.31	
	IL	22	80.55 ± 10.94	

FVR: Feedback-based virtual reality; VR: Virtual reality; IL: Interactive lecture. ^a One-way ANOVA

Table 4 Multiple comparisons for satisfaction scores across groups (post-hoc scheffe)

	Group (I)	Group (J)	Mean Difference (I-J)	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
FVR: Feedback-based virtual reality; VR: Virtual reality; IL: Interactive lecture	FVR	VR	1.36	0.93	-7.77	10.50
		IL	-2.05	0.85	-11.18	7.09
	VR	FVR	-1.36	0.93	-10.50	7.77
		IL	-3.41	0.63	-12.33	5.51
	IL	FVR	2.05	0.85	-7.09	11.18
		VR	3.41	0.63	-5.51	12.33

Discussion

The present study aimed to evaluate the effects of three instructional approaches, FVR, VR, and IL, on triage level estimation accuracy and nursing students' satisfaction. The findings indicate that post-intervention triage accuracy did not differ significantly between the three methods, and that the overall main effect of time was not statistically significant. Specifically, the VR and FVR groups showed higher mean performance scores immediately after the intervention; however, these between-group differences were not statistically significant. The higher immediate score in the FVR group should also be read against its higher baseline score, since that group began training with an advantage that was close to statistical significance. At the one-week follow-up, accuracy patterns differed among groups, with a relative decline in the VR and FVR groups and continued improvement in the IL group. Participant satisfaction was consistently high across all groups, with no significant differences

observed between methods. These results suggest different temporal patterns of learning across instructional approaches; however, given the absence of significant immediate between-group differences, these patterns should be interpreted cautiously.

The observed patterns in triage accuracy can be interpreted using Cognitive Load Theory [34] and Information Processing Theory [35]. The higher immediate mean scores observed in the VR and FVR groups may be partly explained by immersive and multisensory engagement; however, these approaches may also introduce additional cognitive demands when learners navigate complex scenarios without sufficient instructional support. Conversely, the IL, characterized by structured, stepwise guidance, facilitated gradual, deeper processing, thereby supporting modest yet sustained improvements. The comparable levels of satisfaction across different instructional methods suggest that learner engagement is influenced more by instructional clarity, feedback, and scaffolding than by technological sophistication alone, consistent with the principles of Multimedia Learning Theory [36]. These findings underscore the importance of aligning instructional design with the cognitive demands associated with acquiring complex clinical skills. An important consideration in interpreting these findings is that the three instructional approaches differed not only in technological modality but also in the type and level of instructional support provided. The IL group received continuous instructor interaction, clarification, and discussion, whereas the FVR group benefited from structured feedback designed to correct performance and reinforce learning. In contrast, the VR group primarily involved immersive practice without an equivalent structured debriefing component. Therefore, differences in learning trajectories cannot be attributed solely to the presence or absence of technology but may reflect the combined effects of immersion, instructional guidance, feedback, and learner support. Future studies should consider standardizing these educational components to better isolate the specific contribution of technology.

These findings are partially consistent with Chumvanichaya et al. [32], who reported that VR can enhance triage decision-making accuracy and motivation. However, effectiveness may vary with the cognitive complexity of the triage system. Similarly, in the present study, IL appeared to support more accurate estimation of ESI triage levels, possibly reflecting the multi-step, analytic nature of this system, which may benefit from structured explanation, interactive discussion, and guided feedback. Stepwise reasoning and facilitated case analysis in IL may have contributed to deeper cognitive processing, supporting more accurate performance.

Previous research by Behmadi et al. [12] found no statistically significant difference in START triage accuracy between VR and traditional lecture methods, although VR showed a marginally higher performance. This finding is consistent with current results, suggesting that VR may not inherently surpass conventional approaches and that its efficacy may depend on the nature of the instructional material and the specific skills being taught. Similarly, Wang et al. [37] reported that VR more reliably enhances engagement, motivation, and confidence than immediate decision-making, which may explain why VR in the present study did not consistently produce superior performance.

The quality of instructional design and scenario structure may be particularly influential, as noted by Hosseini et al. [38]. In the present study, IL provided immediate feedback and conceptual clarification, which may have contributed to the observed accuracy. Technical challenges, cognitive load, and environmental factors in VR scenarios (cybersickness, usability issues) may limit performance [39]. Although structured feedback in FVR addressed some limitations, it did not yield clearly superior outcomes, indicating that careful scenario design and instructional guidance remain critical [40].

Regarding the current findings, learner satisfaction did not differ significantly across instructional methods. Consistent with this observation, Sudirman et al. found that animated video-based triage education improved knowledge and satisfaction, despite no observable differences in decision-making, suggesting that simpler, visually clear media with minimal technical requirements can effectively enhance satisfaction [41]. Wang et al. also emphasized that structured, interactive interventions combining video feedback and peer role-play promote engagement, self-directed learning, and satisfaction [37]. Although VR and FVR were employed in the present study, the immediacy of feedback and collaborative elements may have been less prominent, potentially limiting their impact. Bani Salameh et al. reported that VR simulations in community and pediatric nursing increased

satisfaction, confidence, and performance [42]. Nonetheless, variations in study design, integration, instructional support, exposure duration, or sample size may account for the lack of significant differences among groups observed in this study. These findings underscore that VR alone does not guarantee increased satisfaction; careful attention to content realism, usability, cognitive load, interaction quality, and pedagogical coherence remains essential.

Domain-specific factors may also influence outcomes. Jallad et al. [43] reported high satisfaction and retention in VR-based anatomy education, which relies heavily on spatial visualization. In contrast, ESI triage requires hierarchical, analytic decision-making, potentially favoring methods that provide structured cognitive scaffolding. User-related factors, including perceived usefulness, self-efficacy, and technical confidence, may further modulate satisfaction and engagement [44].

Instructor involvement is instrumental. The beneficial effects of prompt feedback, facilitated discussion, and social presence have been underscored in prior research [45, 46], which may explain the marginally higher levels of descriptive satisfaction observed in the IL group. Similarly, Yazdanik et al. [47] emphasized that the design of e-learning, encompassing interaction, accessibility, and support, may be more important than the mode of delivery itself.

Collectively, these findings offer several considerations for ESI triage education. VR-based methodologies may augment engagement and facilitate immersive learning experiences; however, their efficacy is likely contingent upon alignment with instructional content, structured feedback, and support for analytical reasoning. For cognitively complex systems such as ESI, instructional strategies that incorporate step-by-step explanations, interactive discussions, and instructor guidance may achieve comparable or superior educational outcomes and learner satisfaction. Future research could investigate integrating VR with structured peer interactions, video feedback, or other supportive elements further to enhance both learning efficacy and the overall learner experience.

Strengths and limitations

This study underscores several notable strengths. It employed a structured quasi-experimental design comprising three intervention arms, adhered to the TREND reporting guidelines, and utilized validated, scenario-based instruments to evaluate triage accuracy and learner satisfaction. Including an FVR group facilitated the examination of the incremental effect of structured debriefing on learning outcomes. Immersive VR environments featuring realistic scenarios enhanced ecological validity and offered students experiential learning that closely simulates clinical practice. Furthermore, standardized testing procedures and meticulous item analysis bolstered the reliability and comparability of outcome measures across the groups.

Notwithstanding, it is important to recognize several limitations. The study was conducted at a single nursing institution, which limits the generalizability of the findings to other educational settings or cultural contexts. The follow-up period was limited to one week, thereby providing limited insight into long-term knowledge retention, skill transfer to clinical practice, or enduring improvements in triage decision-making. While scenario-based assessments were designed to closely emulate clinical situations, they may not fully capture the complexity, unpredictability, and cognitive load characteristic of real emergency settings. Additionally, technical and environmental factors associated with VR usage—including cybersickness, headset discomfort, limited prior exposure to immersive technologies, and session duration—may have impacted participant engagement and performance. Furthermore, participants were not randomly allocated to the study groups. Because assignment followed the existing course sections and the scheduling of the training sessions, the groups may have differed systematically in unmeasured characteristics, and selection bias cannot be excluded. Baseline triage accuracy was in fact not equivalent across groups: the FVR group scored higher before training than the VR and IL groups, and this difference approached statistical significance ($p=0.055$). Although baseline demographic characteristics and GPA were comparable, and baseline accuracy was included as a covariate in the ANCOVA models to reduce the influence of this imbalance, statistical adjustment cannot fully substitute for randomization; residual confounding remains possible, and all between-group comparisons should be interpreted accordingly. The study was also not

powered to detect pairwise between-group comparisons at individual time points; the non-significant differences observed should therefore not be interpreted as evidence of equivalence among the three methods. Lastly, individual learner characteristics such as baseline clinical reasoning ability, prior experience with digital technologies, and intrinsic motivation were not systematically controlled and may have contributed to variability in the observed outcomes.

Conclusion

All three instructional approaches (IL, VR, and FVR) were well accepted by participants. Triage accuracy did not differ significantly between the three methods at either post-intervention time point, and the overall main effect of time was not statistically significant. Although the VR and FVR groups demonstrated higher mean accuracy immediately after the intervention, these between-group differences were not statistically significant. The significant time $\times$ group interaction suggests that the instructional approaches were associated with different learning trajectories over time, with the IL group showing continued improvement at the one-week follow-up. Satisfaction was similarly high across all groups, indicating comparable acceptability of the three educational methods. These findings suggest that VR may serve as a valuable adjunct to ESI triage education; however, larger studies with longer follow-up are needed to clarify its comparative effectiveness and long-term educational impact.

Practice implications

The findings of this research possess substantial practical implications for nursing education. In this study, interactive lecture methodologies, augmented through structured discussions and guided reasoning, were at least as effective as the VR-based methods for teaching complex, hierarchical decision-making tasks such as ESI triage, while requiring substantially fewer technical resources. Additionally, virtual reality, particularly when integrated with scenario-specific feedback, can serve as a supplementary instructional tool to enhance engagement and facilitate immersive experiential learning. Educators are advised to consider employing VR as an adjunct rather than a replacement for traditional educational approaches, ensuring alignment with learning objectives, providing appropriate scaffolding, and ensuring adequate technical assistance. These strategies have the potential to improve nursing students' preparedness for real-world emergencies while accommodating diverse learning preferences.

Recommendations for future research

Future research should conduct multi-institutional studies with larger sample sizes and longer follow-up periods to evaluate the retention of triage skills. Investigations may also explore the synergistic effects of integrating VR with structured peer discussions, video-based feedback, or adaptive learning algorithms to enhance performance and engagement. Moreover, examining user-related factors such as self-efficacy, technological literacy, and cognitive load could facilitate the customization of VR interventions to optimize learning outcomes. Additionally, comparative cost-effectiveness analyses could provide valuable insights for resource allocation decisions in nursing education programs, particularly when implementing immersive educational technologies.

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Declarations

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