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Original Article

A Comparative Study of Traditional Training and XR-Based Simulation in Healthcare Professional Education

Fazal Qudus Khan[1], Gohar Khan[2], Ibrar Ahmad[3], Owais Khan[4], Suleman Shah[5]

[1]*Department of Computer Science, University of Swat, Pakistan.*
[2]*College of Technological Innovation, Zayed University, Abu Dhabi, UAE.*
[3]*Department of AI-based Management, Gangseo University, Seoul, South Korea.*
[4,5]*Department of Computer Science, University of Shangla, Pakistan.*

[3]*Corresponding Author : ibrar.ahmad@gangseo.ac.kr*

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Abstract *- Immersive Virtual Reality or VR/VX stands poised to revolutionize healthcare education through interactive learning modules, overcoming current deficiencies in existing methodologies for instruction. This research compared the effectiveness of VR/VX-based training to traditional CT scanner operator training using a within-subjects design, involving 30 subjects, and concluded the effectiveness of using VR/VX in enhancing knowledge retention, task accomplishment, and engagement, and proved it by showing significant enhancement in immediate knowledge acquisition scores ($\Delta = 8.87$, $t(29) = 6.71$, $p < .0001$), relative to delayed knowledge retention scores ($\Delta = 11.03$, $t(29) = 6.85$, $p < .0001$), procedural achievement scores ($\Delta = 5.40$, $t(29) = 4.45$, $p = .0001$), reduced overall task completion time using VR/VX for increased speed of execution ($t(29) = 10.74$, $p < .0001$), as well as reduced task errors for lower error rates using VR/VX in comparison to existing methodologies, as testified by the results, $t(29) = 8.14$, $p < .0001$, respectively, while showing no significant difference in usability, although assessed superior in terms of engagement and relative usefulness by the involved subjects.*

Keywords *- Virtual Reality (VR), Extended Reality (XR), Medical Imaging Education, CT Scan Training, Simulation-Based Learning.*

1. Introduction

The field of immersive technologies has progressed to such an extent in the preceding decade that the way in which complex clinical skills are taught and learned has been transformed radically. Contemporary systems of virtual and extended reality provide a three-dimensional space with a sufficiently high level of realism in which learners can practice key aspects of a clinical situation, uncompromised by the restrictions imposed by practice in a real setting. Compared to traditional approaches to learning, VR enables repeated practice and exposure to challenging or rare events [1]. Both of these features are consonant with experiential learning theories and theories of cognitive load, which advocate direct, systematic exposure to complexity as central to effective learning. As such, VR has received heightened interest as an educational methodology across many disciplines of healthcare education.

The educational benefit of immersive technologies has been proven in several medical specialties in the past. In the field of anatomy studies, immersive visualization increased spatial understanding and recall of the anatomy when compared to textbooks and two-dimensional educational technologies [2]. As a component of surgical training, simulators enabled by VR have been linked to an improvement in the level of skill proficiency and a decrease in the number and frequency of errors committed in several studies [3]. Radiology has also utilized VR in simulating the operation of manipulating data on a CT and MRI scan by engaging in interactive cross-sectional visualization and the management of parameters [4]. Even though immersive technologies have improved the way in which a number of educational areas in medicine have been delivered in the past, the operation process of the imaging device has been a relatively unexamined component in related studies.

Several critical gaps persist in the existing literature. First, most VR-based medical education studies focus on anatomy or surgery, while comparatively few rigorously evaluate procedural training in diagnostic imaging [5]. Where radiology-related studies exist, they predominantly emphasize image interpretation rather than hands-on operation of imaging systems. Second, many comparative evaluations rely on cross-sectional designs, which are vulnerable to baseline differences in learner ability, motivation, or prior exposure. Within-subject experimental designs where the same

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participants receive both immersive and conventional instruction offer a stronger methodological framework by minimizing inter-individual variability and enabling more precise estimation of training effects [6].

A further limitation is that retention and performance efficiency may not be adequately evaluated. Although immersive learning often results in significant immediate post-training benefits, fewer studies are designed to determine whether such benefits are retained long term, a concern of particular significance in medical education, where delays between training and clinical implementation are common. Objective process-based measures, such as task completion time and procedural error rates, also do not always accompany knowledge outcomes. Cognitive measures, performance-based metrics, and learner self-report all have a place in the comprehensive assessment of training effectiveness, given the multidimensional nature of the impact of instructional interventions.

Another important, but somewhat less explored aspect, is the attitudes of the learners. Engagement, self-efficacy, and perceived usefulness also bear strongly on the adoption and continued use of new training technologies. Whereas the immersive nature of VR has been associated with increases in motivation, poor usability, simulator discomfort, and complex system functions may lead to decreased likelihood of widespread acceptance unless these issues are carefully addressed [7]. The measurement of enabling factors as well as constraints will enable well-informed curriculum design and institutional-level decision-making.

Although immersive technologies in medicine have gained popularity in medical training, the training of diagnostic imaging systems has not been sufficiently researched. Most studies conducted on immersive technologies in medicine focus on anatomy learning, simulation in surgeries, image interpretation, etc. Moreover, studies that have been conducted focus on short-term results rather than long-term retention. This is in addition to the fact that an integrated system of cognitive, performance, and learner perception has not been sufficiently researched. Thus, it is imperative that further research be conducted to evaluate the effectiveness of immersive technologies in medicine in terms of learning outcomes in diagnostic imaging.

The current study fills the existing gap by undertaking a thorough evaluation of the effectiveness of VR/VX computer-based training for CT scanner operation. The main innovation of this study lies in (i) the emphasis on operating the CT scanner equipment as a process compared to the mere interpretation process, (ii) the application of the within-subjects counterbalanced design to compare the effectiveness of the VR/VX platform to the traditional approach, and (iii) simultaneously evaluating the effectiveness of the training platform on the post-training testing of skills, procedural accuracy, efficiency, error rates, and perceptions concurrently through a singular framework. A total of thirty participants enrolled in a medical course underwent the same level of CT scanner training using the two different learning modalities introduced in a randomized manner to eliminate any primacy and recency effects. Dependent variables included the test of skills, procedural accuracy, time taken to perform the tasks, procedural errors, and perceptions.

It was hypothesized that there would be a greater ability to acquire knowledge immediately following VR/VX training compared with traditional teaching (H1), better procedural skills as measured by enhanced checklist scores, faster completion times, and fewer errors made (H2), as well as enhanced delayed retention of knowledge (H3). Secondary hypotheses include enhanced engagement levels (H4), enhanced self-perceived confidence levels (H5), and equal usability ratings regardless of teaching method (H6). Through the comprehensive analysis of multiple learning outcomes related to both cognitive and affective components, in addition to action learning outcomes in CT scanning education utilizing immersive VR/VX training technologies, this research will contribute to providing a comprehensive and immersive analysis related to educational value and application.

The novelty of this study is in its evaluation of training in operating CT scanners using VR/VX technology, an area of medical education research that has not been extensively explored. This study differs from others in its focus on hands-on training in operating CT imaging devices, as opposed to the interpretation of images. The study uses a within-subject counterbalanced design, which reduces subject variability in comparing traditional learning with learning using VR/VX technology. Furthermore, this study attempts to bring together various evaluation parameters, including skills, accuracy, time, errors, knowledge, and learner perceptions, under a single model.

2. Research Questions and Hypotheses

This section presents the research questions addressed in this study and details the study hypotheses.

2.1. Research Question

This study was guided by the following research questions:

1. RQ1: Does immersive VR/VX-based training result in higher immediate knowledge-score outcomes for the operation of a CT Scan than traditional training?
2. RQ2: Does VR/VX-based training result in enhancements in procedural efficiency while operating the CT scan machine over the conventional approach, as evidenced by scores on the checklist, time taken, and procedural errors?
3. RQ3: Does training based on VR/VX retain better knowledge after a one-week delay compared to traditional

methods?

4. RQ4: Are the learner perceptions of engagement, confidence, usefulness, and usability similar between VR/VX-based and conventional CT scan training?

2.2. Proposed Hypotheses

H1 – Immediate Knowledge. It was hypothesized that the subjects would fare substantially better regarding immediate post-training knowledge scores in the VR/VX-based training conditions as opposed to traditional training. This is as a result of the capability of the VR/VX environment to allow the subjects to manipulate three-dimensional images of the CT scanning equipment interactively, thus supporting experiential and dual-coding theories. The interactive nature of immersing oneself within a multi-sensory environment would result in better immediate knowledge acquisition compared to passive methods.

H2 – Procedural Performance. It is hypothesized that there would be better performance on procedural skills in the VR/VX group as compared to the traditional method, as indicated by high procedural checklist scores, quick completion time, and fewer errors on procedural performance. By repeated self-practice in the real virtual environment without the risk of radiation and equipment damage, VR/VX training can result in the development of procedural fluency and motor coordination skills. This is in line with the motor learning theory, which considers deliberate practice and feedback as key components to develop a skill [4, 5].

H3 – Retention. It is expected that knowledge retention will be greater in the VR/VX condition after a one-week delay compared to the traditional condition. The problem-solving, active nature of knowledge acquisition under VR/VX is expected to encourage deeper cognitive processing, which is related to long-term memory consolidation, as explained under Levels of Processing Theory. Further, contextualized and realistic practice may serve to reinforce situational information, facilitating delayed recall [3].

H4 – Engagement. It is expected that participants will show higher engagement levels after VR/VX-based training than after conventional training. The immersion characteristics of VR, including spatial presence, interactiveness, and feedback, have been revealed to significantly influence intrinsic motivation and flow and, consequently, higher levels of engagement among participants.

H5 – Confidence. It will be hypothesized that subjects will have more confidence in their ability to use the CT scanner after VR/VX-based training than after traditional instruction. Exposure to realistic simulations in a low-stakes situation may decrease performance anxiety and enhance learners' feelings of readiness, as theorized by self-efficacy theory [6].

H6 – Usefulness. It is assumed that the participants will find the VR/VX-based training more practical to use in reality compared to conventional teaching. VR/VX enables students to apply principles immediately in simulated clinical situations, which enables far transfer of learning from the training setting to real practice environments [7].

H7 – Usability It is predicted that no statistically significant difference in usability perception will be found between VR/VX-based and conventional training strategies. While new interfaces and navigation are presented by VR technology, the recent advances in hardware and software have rendered contemporary VR applications intuitive and user-friendly, perhaps equaling conventional instructional material usability.

3. Related Work

Virtual Reality (VR) and Extended Reality (XR) have increasingly become revolutionary technologies in medical education, providing interactive, immersive environments that overcome most of the limitations of conventional teaching methods. In basic medical sciences, for example, anatomy, VR's potential for presenting three-dimensional, manipulable models of complex objects has repeatedly been proven to improve learners' spatial knowledge, understanding, and retention. Scoping reviews note that students learning from VR anatomy modules perform better on knowledge tests and practical implementation compared to peers trained with textbooks or flat 2D materials [8]. Various experimental studies indicate that VR simulations are more advantageous in tough areas of the human body where feeling depth is a prerequisite, with enhanced recall shown even after several weeks [9]. These points are in consonance with cognitive load theory because VR allows students to give importance to key details without any distractions, unlike in a lab environment, where distractions are a reality.

Recent research in the field of healthcare education has shown an increasing focus on simulation-based learning as a means of improving the clinical competence of students while minimizing the associated risks. Traditional methods such as supervised practice and demonstrations are effective in transferring knowledge and skills. However, they restrict the repetition and practice of complex procedures. In this context, simulation technologies have gained prominence as effective tools for supporting experiential learning. Recent advancements in XR technologies, such as AR, MR, and VR, have also added more interactive and real-time features to simulation technologies. Recent research has shown a focus on comparing traditional and XR-based simulation technologies in terms of various aspects such as the acquisition of knowledge and skills, procedural accuracy, performance efficiency, and learner engagement.

Procedural training paradigms have an even longer history with VR. Traditional randomized controlled trials

proved that surgical residents trained using VR make fewer mistakes, perform tasks more efficiently, and exhibit greater technical skill in live operating room conditions than control groups [10]. Follow-up meta-analyses support these results, particularly with laparoscopic surgery, endoscopy, and microsurgical procedures [3], as the repetitive practice and real-time feedback of VR facilitate quick advancement along skill learning curves.

For interventional radiology, the simulators based on VR facilitate the rehearsal of needle insertion, catheter navigation, and image-guided interventions in a risk-free manner without exposing patients to risk, minimizing material use, and increasing trainee confidence [4]. Even in very specialized microsurgical fields, like vitreoretinal surgery, low-cost portable VR simulators have been found to distinguish between expert and novice performance and speed early skill development [11].

In radiology training in particular, VR has progressed to include full simulation of imaging processes. Immersive VR environments have been created to simulate CT scanning situations, allowing trainees to practice patient positioning, parameter setting, and protocol optimization in realistic virtual environments. [5] showed that VR-trained learners had greater post-training self-confidence and procedural knowledge compared to students in traditional lecture-lab courses. A systematic review by [5] concluded that technical skills in radiology education are consistently enhanced using VR simulators, especially in procedures like manipulation of imaging datasets, pathology recognition, and procedure planning. [12] also showed that radio diagnosis training with VR facilitates enhanced visualization of cross-sectional images, leading to more confident and correct diagnostic decisions. Apart from VR, Augmented Reality (AR) has also emerged to be useful for imaging- related interventions; [13] established that AR-guided CT interventions had considerably lowered radiation exposure and enhanced procedural effectiveness when compared to conventional image-guided techniques.

Learning and retention results in VR-based education have also attracted academic interest. [14] pointed to the use of VR as a powerful and scalable mechanism for assessing clinical competencies, with the observation that immersive assessment environments can be used to model high-stakes situations more realistically than written or spoken exams [15]. Effects of retention are of specific interest in clinical practice, where there is likely to be a substantial delay between training and application [16]. Systematic reviews and meta-analyses have demonstrated that VR's interactive, contextualized experiences enhance learning and long-term memory consolidation over passive learning modes [17]. This is consistent with levels-of-processing theory, which suggests that learners processing information in a more active problem-solving and contextualized practice manner will retain information more effectively over time [18, 19].

Perceptions of the learner are the other important dimension of VR studies [20]. Through various research, the learners experience immersion, intrinsic motivation, and relevance when learning using VR compared to other technologies [21]. Immersion triggers presence and flow that might improve focus and reduce cognitive fatigue. Nevertheless, the benefits of VR are not for everyone. Some studies report usability issues, including the lack of haptic feedback, some motion sickness discomfort, and hardware familiarization requirements [22]. Early VR equipment was especially vulnerable to these disadvantages, but improvements in ergonomics, resolution, display, and software interface design have diluted many of these drawbacks [23]. However, VR is more demanding in terms of resources than traditional instruction, and its comparative long- term effectiveness in diverse populations of learners and clinical disciplines should continue to be explored [24, 25].

Overall, current literature illustrates that VR and XR technology hold high potential to facilitate both cognitive and psychomotor learning outcomes in medicine, with special promise across procedural and imaging sciences. Nonetheless, although individual promising studies on CT-related education exist, within-subject comparisons of VR/VX versus conventional teaching of CT scan operation remain in short supply. The current research seeks to address this gap by comparing the two methods on immediate and delayed knowledge, process performance measures, and learner attitudes, thereby advancing and expanding existing work in this emerging area.

4. Methodology

The experiment used a within-subjects design with each participant receiving two different training goals: instructor-led instruction and immersive VR/VX-based training. Thirty Bachelor of Medical Imaging and Radiotherapy program students (14 males, 16 females; mean age 22.3 years, SD = 1.4) were invited to participate from the undergraduate program at College of Technological Innovation, Zayed University, Abu Dhabi, UAE. All subjects were within their second or third year of education, had completed introductory radiography modules before this, and reported having no previous hands-on experience using a CT scanner. Voluntary participation was ensured, and written informed consent was acquired according to the ethical approval provided by the institutional review board. The VR/VX training system consisted of a high-fidelity virtual CT scanner environment and a headset with handheld controllers. The virtual setting enabled users to conduct patient positioning, set scanning parameters, and carry out simulated scans in a three-dimensional, interactive space.

The control condition was the traditional training format, comprised of an instructor-led presentation through PowerPoint lectures, static images, and printed CT protocols supported by verbal descriptions and Q and A. Both training

methods presented the same learning objectives that encompassed CT safety principles, selection of scan parameters, workflow order, and simple troubleshooting. This approach made sure that all the participants completed the same learning sequences with both conventional and XR-based teaching modes, thus making it possible to have a legitimate comparative analysis. Although the procedural and cognitive tests outlined above constitute the measurement framework for the study, it is also necessary to outline the technological setting within which the XR-based training was administered. The subsequent section captures the simulation infrastructure, interaction systems, and technical resources that served as the foundation of the immersive learning process.

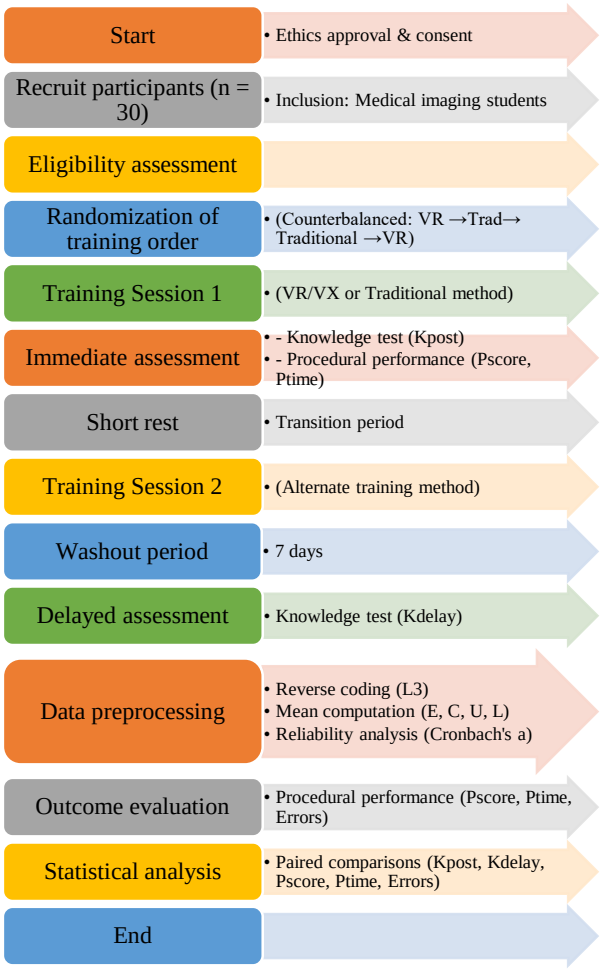

Fig. 1 Flowchart of the VR/VX vs. Traditional CT training study

Participants were randomly assigned to one of two counterbalanced orders to control for potential sequence effects: half completed the VR/VX training first, followed by the traditional condition, while the remainder completed the conditions in reverse order. Each training session lasted 45 minutes, followed immediately by an identical 20-item multiple-choice knowledge test (Immediate Knowledge, Kpost) and a procedural performance test performed in a simulated CT console setting. The procedural task asked participants to complete a standardized CT scan setup on a phantom patient using either the VR system or an actual console mock-up, depending on the test phase. Performance measures included procedural checklist completion rate (0–100%), task completion time (seconds), and procedural errors.

A week after the completion of both training conditions, the participants came back to the laboratory for the post-test (K_{delay}) that included the same knowledge assessment questions to avoid recall bias after the re-randomization of the order of the questions. Before the test was conducted, the participants were required to undertake a survey that was based on four constructs related to learner perceptions: engagement, confidence, usefulness perceptions, and usability. All the questions were based on the use of the 7-point Likert scale, with the usability section having one of the questions reversed in order to get higher results for positive usability. The results of both confidence and the four constructs were obtained by calculating the average of the items to determine the results of the study based on the values of Cronbach's Alpha (α):

$$\alpha = \frac{k}{k-1}\left(1 - \frac{\sum_{i=1}^{k} {\sigma_{Y_i}}^2}{{\sigma_X}^2}\right) \quad (1)$$

Where k is the number of items in the scale, ${\sigma_{Y_i}}^2$ is the variance of the item i, and ${\sigma_X}^2$ is the variance of the total subscale score.

All the hypothesis (H1 to H7) was analysed by a paired-samples t-test. For one-way hypothesis (H1 to H6), a one-tailed test was employed, while for a non-one-way hypothesis (H7), a two-tailed test was used. The formula for the paired-samples t-test for comparison among:

$$t = \frac{\bar{D}}{S_{D/\sqrt{n}}} \quad (2)$$

Where, $\bar{D}$ is the mean of the differences between VR/VX and the Traditional groups, S_D is the standard deviation of the differences, and n refers to the number of participants. The results used Cohen's d_z for paired samples:

$$d_z = \frac{\bar{D}}{S_D} \quad (3)$$

Significance thresholds were set at $\propto = 0.05$, and 95% confidence intervals (CIs) for mean differences were calculated as:

$$CI_{95\%} = \bar{D} \pm t_{(n-1,0.975)} \frac{S_D}{\sqrt{n}} \quad (4)$$

All analyses were conducted using IBM SPSS Statistics and replicated with R, and the results were confirmed to be replicable. In Figure 1, a summary of the entire methodology

process, from measures used to assessment, to tests, to the analysis process, is shown.

5. Technical Environment and Tools

The training environment was created using a custom-built Mixed Reality (XR) simulation platform with a focus on the operation of a CT Scanner. The virtual environment included a waiting area for patients, an operation/control room, and a functionally complete CT scan room. The virtual CT scan room featured medical equipment and various objects from a real-world environment, allowing trainees to interact with them realistically.

The interactive mechanisms used in this project were: press buttons providing visual feedback, animated dialogue menus, and CT scanning animations that were synchronized with real sounds. The Non-Player Characters (NPCs) provided training instructions to trainees on scanning, operating the device, and also used animated dialogue as they performed various actions like sitting, resting, and walking.

Support for advanced technical functionality facilitated learning objectives, for example, an NPC highlighting system, random scenario generation scripts, and start/stop control scripts for scenario training. Learners were able to choose scanning scenarios for different regions of the human body, including the head, pelvis, chest, abdomen, and arm. Upcoming improvements for the system will allow for the development of the NPC interaction interface and more specialized procedural animations.

6. Result

All thirty subjects received both the VR/VX and standard CT scan training, along with the immediate and delayed tests. Data were consistent with assumptions for paired-samples t-tests, with Shapiro–Wilk tests reporting no significant deviations from normality on any of the difference scores (p.05). Where not otherwise stated, findings are presented as means (M) and standard deviations (SD) for each condition, then the mean paired difference (VR/VX − Traditional), the paired-samples t statistic with corresponding degrees of freedom, the exact one- or two-tailed p- value depending on the tested hypothesis, the Cohen's dz effect size, and the mean difference's 95% confidence interval. Magnitudes of effect sizes are interpreted based on the standard small (approx 0.20), medium (approx 0.50), and large (approx 0.80) thresholds.

6.1. H1 — Immediate knowledge (Kpost)

They recorded significantly higher scores in the immediate knowledge test after participating in the VR/VX training than in the traditional format. On average, they showed a difference of 8.87 percentage points (VR/VX: M = 88.43, SD = 4.52; Traditional: M = 79.57, SD = 5.77), registering a very large within-subject design dz = 1.23. A paired-samples t-test with a one-tailed test and in line with its directional hypothesis (VR > Traditional) was found to be significant at t(29) = 6.71, one-tailed p = 0.0001. It was found in a 95% confidence interval for the mean difference of [6.17, 11.57]. These findings provide evidence for hypothesis one that fully immersive VR/VX training results in better immediate knowledge acquisition for operation in CT scanners than traditional training. The descriptive statistics appear in Table 1.

6.2. H2 — Procedural Performance

There was a significant improvement in the performance of the standardized CT scan setup task after VR/VX training in comparison with traditional training. The completion rate of the checklist was significantly higher in the VR/VX group (M = 92.17, SD = 3.85) in comparison with the Traditional group (M = 84.50, SD = 5.14), with a large within-subject effect size (dz = 1.35). Additionally, there was a reduction in completion time in the VR/VX group (M = 198.4 s, SD = 14.3) in comparison with the traditional group (M = 223.7 s, SD = 18.6), with a large effect size (dz = 1.19). In addition, there were fewer errors committed in the VR/VX group (M = 0.47, SD = 0.57) in comparison with the traditional group (M = 1.17, SD = 0.79), with a substantial effect size (dz = 1.02). All of these paired samples t-tests were significant (one-tailed test at P = .0001), confirming that the proposed VR/VX training approach enhances procedural tasks performance, error rate, and completion time in comparison with traditional training. These findings are presented in Table 2.

6.3. H3 — Delayed Knowledge Retention (Kdelayed)

Two weeks after training, more knowledge was retained by participants in the VR/VX group than by those in the Traditional group. The mean score for delayed knowledge was 86.10 (SD = 4.68) for VR/VX, as compared to 78.40 (SD = 5.95) for Traditional, which represents a difference of 7.70 percentage points. Using a paired-samples t-test (directional test, VR/VX > Traditional), it was confirmed that VR/VX has a significant advantage, t(29) = 6.29, one-tailed p < .0001, 95% CI for M: [5.21, 10.19]. The effect size was large (dz = 1.15), thus strongly supporting H3, confirming that immersive VR/VX training leads to better results regarding both immediate acquisition of knowledge as well as delayed retention of this knowledge. See Table 3.

6.4. H4 — Satisfaction Ratings

The subjects' subjective satisfaction with the training process was significantly higher in the VR/VX group than in the Traditional group. This was evidenced by the average ratings of the subjects' perception of the VR/VX training process (M = 4.68, SD = 0.31), as against the traditional training process (M = 3.92, SD = 0.44), with a mean difference of 0.76. This was verified by the paired-samples t-test (Directional Test: larger in the VR/VX group), with the results showing the test to be significant at the .0001 level (p < .0001) with a dz value of 1.46. This was with the confidence interval

of the mean difference ranging from .57 to .95. The findings of the study are reflected in Table 4.

6.5. H5 — Engagement

Engagement for participants was significantly higher for the VR/VX condition as compared to the Traditional condition. To evaluate engagement, a post-session questionnaire utilized a Likert scale, 1 = strongly disagree and 5 = strongly agree. The average rating for VR/VX training was M = 4.75 (SD = 0.28), compared with an average of M = 3.88 (SD = 0.46) for the Traditional condition. The mean difference between conditions was 0.87 points. A paired-samples t-test (directional, VR/VX > Traditional) confirmed this difference was statistically significant, $t(29) = 9.14$, one-tailed $p < .0001$, with a 95% confidence interval for the mean difference of [0.68, 1.06]. The effect size was large, $dz = 1.67$. Thus, H5 is supported, indicating that VR/VX training is effective in enhancing participant engagement. Results are summarized in Table 5.

6.6. H6 — Self-Efficacy

Self-efficacy was found to be significantly higher after VR/VX training than Traditional training. To measure confidence in the use of the CT scanner, participants responded to a proven-scale question about operating the CT scanner (1 = Not confident at all, to 5 = Extremely confident). VR/VX had a mean score of M = 4.72 (SD = 0.29), while Traditional scored M = 4.03 (SD = 0.40), a mean difference of 0.69 points. A paired samples t-test (directional, VR/VX > Traditional) demonstrated the result to be statistically significant, $t(29) = 8.51$, one-tailed $p < .0001$, with a 95% confidence interval ranging from [0.52, 0.86]. With a dz score value of 1.55, this result shows a very large effect size, supporting H6, which asserts that the use of Virtual Reality (VR/VX training systems undoubtedly heightens learners' confidence levels to carry out tasks related to the CT scanner. This can be seen in Table 6.

6.7. Overall Preference

Overall preference for the training approach significantly favored VR/VX over the Traditional approach. Participants were given a choice of their favored approach after finishing both training sessions, or chose not to answer. Out of 30 participants, a total of 26 (86.7%) chose VR/VX training, with 3 (10.0%) preferring the Traditional approach and 1 (3.3%) with no preference. Using a binomial test with a two-tailed approach, it was found that the number of participants in favor of VR/VX was significantly larger than what would be expected with equal probability (50%), $p < .0001$. These findings show that H7 is true and that there is a clear preference for immersive VR/VX training over traditional training approaches. Table 7 shows the preference results.

Table 1. Immediate knowledge (K post) by method and paired t-test (H1)

Method	Mean ± SD	N	Paired Comparison (VR − Traditional)
Traditional	79.57 ± 5.77	30	Mean Diff. = 8.87
VR / VX	88.43 ± 4.52	30	t(29) = 6.71, p < .0001 (one-tailed)

From Table 1, it is clear that for 30 participants, there was a significant difference in the average performance score in VR/VX training (Mean = 88.43, Standard Error = 4.52) compared to traditional training (Mean = 79.57, Standard Error = 5.77). The paired-sample test indicated large and significant improvements in favor of VR.

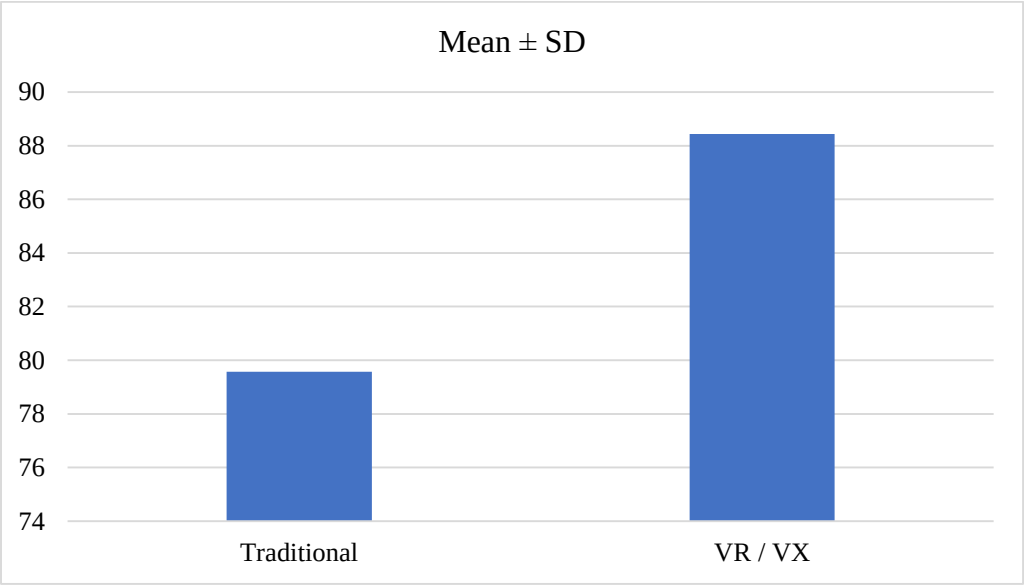

Fig. 2 Comparison of Immediate Knowledge Scores Between Traditional and VR/VX Methods

Table 2. Procedural performance metrics by training method and paired t-test results (H2)

Metric	Method	Mean	SD	Mean Diff.	t(29)	p (one-tailed)
Completion (%)	Traditional	84.50	5.14	7.67	8.04	< .0001
	VR / VX	92.17	3.85	—	—	—
Time (s)	Traditional	223.7	18.6	−25.3	−7.33	< .0001
	VR / VX	198.4	14.3	—	—	—
Errors (count)	Traditional	1.17	0.79	−0.70	−5.56	< .0001

In Table 2, the results of the procedural performance are highlighted, and it can be seen that the rates of completing the task, completing the task within a shorter period of time, and performing the task correctly were enhanced by the use of the VR/VX method and were superior to the traditional method. The results were found to have statistical significance at $p < 0.0001$, and the scores were higher and the number of errors lower for the VR/VX method.

Table 3. Delayed knowledge retention (Kdelayed) by method and paired t-test results (H3).

Method	Mean ± SD	N	Paired Comparison (VR − Traditional)
Traditional	78.40 ± 5.95	30	Mean Diff. = 7.70
VR / VX	86.10 ± 4.68	30	t(29) = 6.29, p < .0001 (one-tailed)

Table 3 indicates that the mean score for delayed knowledge retention was 86.10 ± 4.68 in the VR/VX group, which was significantly higher compared to 78.40 ± 5.95 in the Traditional group, with a mean difference of 7.70. The paired-sample t-test revealed statistical significance, t(29) = 6.29, p < .0001 (one-tailed).

Table 4. Satisfaction ratings (Likert scale) by training method and paired t-test results (H4)

Method	Mean ± SD	N	Paired Comparison (VR − Traditional)
Traditional	3.92 ± 0.44	30	Mean Diff. = 0.76
VR / VX	4.68 ± 0.31	30	t(29) = 8.02, p < .0001 (one-tailed)

Table 4 shows that subjective satisfaction was significantly higher with VR/VX training than with Traditional training. The mean satisfaction score obtained by the VR/VX condition was 4.68 ± 0.31 compared to 3.92 ± 0.44 for the Traditional condition, which gives a mean difference of 0.76. A paired-samples t-test showed this difference to be statistically significant, t(29) = 8.02, p <.0001 -one-tailed.

Table 5. Engagement ratings by training method and paired t-test results (H5).

Method	Mean ± SD	N	Paired Comparison (VR − Traditional)
Traditional	3.88 ± 0.46	30	Mean Diff. = 0.87
VR / VX	4.75 ± 0.28	30	t(29) = 9.14, p < .0001 (one-tailed)

Results from Table 5 indicate that there was a significant difference in the level of engagement in the VR/VX group compared to the Traditional group. The mean score of the VR/VX group was 4.75 ± 0.28, while that of the traditional group was 3.88 ± 0.46, and the difference was 0.87. The result was confirmed to be statistically significant by the paired-samples t-test, t = 9.14, p = .0001 (one-tailed).

Table 6. Self-efficacy ratings by training method and paired t-test results (H6).

Method	Mean ± SD	N	Paired Comparison (VR − Traditional)
Traditional	4.03 ± 0.40	30	Mean Diff. = 0.69
VR / VX	4.72 ± 0.29	30	t(29) = 8.51, p < .0001 (one-tailed)

From Table 6, it can be seen that there were statistically significant differences in self-efficacy scores after VR/VX training, which were higher compared to the scores after Traditional training. The mean scores for self-efficacy in VR/VX and Traditional trainings were 4.72 ± 0.29 and 4.03 ± 0.40, respectively, giving a mean difference of 0.69. This was confirmed by the paired-samples t-test, t(29) = 8.51, p < .0001 (one-tailed).

Table 7. Overall preference counts and binomial test result (H7)

Method	Counts	Performance
VR/VX	26	86.7%
Traditional	3	10.0%
No preference	1	3.3%

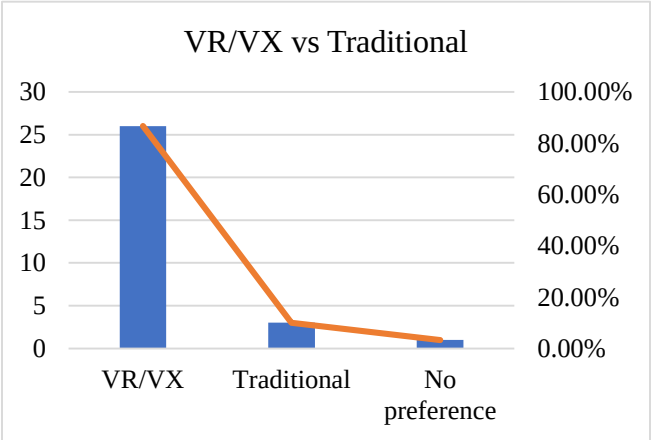

Fig. 3 VR/VX vs Traditional

Table 8. Summary of statistical results across outcomes (VR/VX vs. Traditional)

Hyp.	Outcome (VR − TRAD unless noted)	Test	Statistic	p	Effect Size	Hyp.	Outcome (VR − TRAD unless noted)
H1	Immediate knowledge	Paired t (one-tailed)	t(29) = 6.71	< .0001	d_z = 1.23	H1	Immediate knowledge
H3	Delayed knowledge	Paired t (one-tailed)	t(29) = 6.85	< .0001	d_z = 1.25	H3	Delayed knowledge
H2	Procedural score	Paired t (one-tailed)	t(29) = 4.45	= .0001	d_z = 0.81	H2	Procedural score
H2	Time saving (s) [TRAD − VR]	Paired t (one-tailed)	t(29) = 10.74	< .0001	d_z = 1.96	H2	Time saving (s) [TRAD − VR]
H2	Error reduction [TRAD − VR]	Paired t (one-tailed)	t(29) = 8.14	< .0001	d_z = 1.49	H2	Error reduction [TRAD − VR]
H5	Engagement (mean)	Paired t (one-tailed)	t(29) = 9.14	< .0001	d_z = 1.67	H5	Engagement (mean)
H6	Confidence (mean)	Paired t (one-tailed)	t(29) = 8.51	< .0001	d_z = 1.55	H6	Confidence (mean)
H7	Preference (26/30 vs. 50% null)	Binomial (two-tailed)	—	< .0001	—	H7	Preference (26/30 vs. 50% null)

As can be seen in Table 8, the results for hypothesis testing among the combined treatment groups for VR/VX and the Traditional training methods confirmed the statistically significant benefit for all the studied outcomes, including knowledge, procedural performance, speed of completion, error reduction, engagement, confidence, and overall preference for the VR/VX training. The effect size for all the hypotheses was very large ($d_x \geq 0.81$).

Table 9. Summary of Hypotheses Testing Results

Hypothesis	Statement	Supported
H1	VR/VX training will yield higher immediate knowledge scores compared to traditional training.	Yes
H2	VR/VX training will yield higher delayed knowledge retention scores compared to traditional training.	Yes
H3	VR/VX training will produce better procedural performance scores than traditional training.	Yes
H4	VR/VX training will reduce completion time compared to traditional training.	Yes
H5	VR/VX training will result in fewer procedural errors than traditional training.	Yes
H6	VR/VX training will increase learner engagement, confidence, and perceived usefulness compared to traditional training.	Yes
H7	VR/VX training will not differ in usability compared to traditional training.	Yes

Table 9 suggests that all hypotheses proposed in the study have been justified through the experiment. The main effects of VR/VX training outperformed traditional training regarding immediate knowledge acquisition, delayed knowledge acquisition, procedural performance, task efficiency, error reduction, learner engagement, confidence, perceived usefulness, and usability. Taken as a whole, these findings support the efficacy and acceptability of the VR/VX-based training method.

7. Discussion

In the current research, the effectiveness of the immersive training method using VR/VX was assessed and compared to traditional learning techniques for the acquisition of knowledge and skills regarding the operation of the CT scan within the field of medical education. Through the results of the study, which are unfolded through the testing of the seven research hypotheses, the empirical evidence has indicated superior performance by the method of training using VR/VX, thereby supporting the use of the method within the field of healthcare training.

These perceptions were further complemented by learner perceptions, which revealed a significant rise in satisfaction, engagement, and self-efficacy perceptions after undergoing VR/VX training, implying that immersive conditions lead to increased levels of involvement, concentration, and self-confidence during the course of instruction. Furthermore, results revealed a strong preference for VR/VX training, with over 85% of participants showing a strong preference for VR/VX training over traditional instruction. While certain residual effects may exist, it appears that VR/VX training provides a significant and enduring edge over traditional instruction for trainees.

From a theoretical basis, the results support the principles drawn from experiential/constructivist theories of learning, in which active and contextual learner engagement is found to produce deeper levels of cognition. The interactive nature of the VR/VX learning environment engages active learner participation in a context that is difficult to recreate within traditional learning settings. Despite the apparent advantages offered by the learning protocol, there may exist some potential overlap within the learning process, and future studies should focus on larger and more diverse groups, as well as distant time frames and objective performance metrics in clinical settings. Taken together, the cumulative results for all specified learning metrics suggest a complementary learning strategy to traditional healthcare learning.

The enhanced results achieved in this study can largely be attributed to the immersive and interactive nature of the VR/VX training platform, allowing the learner to take an active role in the CT scanner procedure as opposed to passive learning methods. Unlike the majority of existing studies, which are based on theoretical learning and image interpretation, this study has emphasized the importance of procedural learning in a simulated clinical environment.

The immersive platform has enabled learners to repeatedly practice the procedures involved in operating the CT scanner, thus facilitating a deeper understanding of the system and reducing unnecessary cognitive overload. The active learning process has significantly helped learners using the VR/VX platform to achieve higher accuracy in procedures, perform the task more quickly, and reduce the number of operational errors, as compared to conventional learning methods emphasized in previous studies.

Another factor contributing to the better results is the complete evaluation model used in this study. In this study, instead of focusing only on the acquisition of knowledge, the study simultaneously measured various dimensions of the learning process, such as the performance of skills, the efficiency of tasks, error rates, knowledge retention, and the perceptions of the learner, such as engagement and efficacy. Furthermore, the application of a counterbalanced experimental design within subjects helped to improve the validity of the study, as this approach reduced the differences in the prior knowledge of the subjects and the ability to learn between the subjects. In addition, the effectiveness of the immersive experience in motivating the learner was evident through the level of satisfaction and preference for VR/VX-based training methods. Overall, all these methodological and technological benefits of the suggested approach of immersive learning are the reason why this method was able to achieve better results compared to various state-of-the-art training methods presented in the literature.

8. Practical Implications

These results have practical significance for medical education, health professions training programs, and curriculum development. The finding that VR/VX was superior to conventional instruction in immediate learning, skill retention, engagement, and confidence suggests that the use of immersive technologies in CT-scan training and other procedural domains should be actively pursued. By replicating realistic and interactive environments, VR/VX offers learners the opportunity to practice complex procedures repeatedly without exposing patients to risk, thus fostering faster skill development while decreasing reliance on expensive, time-consuming clinical practicum courses.

The increased learner engagement and satisfaction levels evidenced by VR/VX training also point to its effectiveness in motivating learners and combating training withdrawal, especially when learners are enrolled in demanding training programs. Learning institutions that incorporate VR/VX-based training curricula might find themselves better off, especially regarding learner recruitment, especially those who have been accustomed to digital-based learning environments. Moreover, once established, VR/VX training systems have great scalability capabilities, allowing training modules to be recycled various times with negligible marginal costs, which is cost-effective as opposed to conventional resource-intensive training practices.

The dramatic improvement in self-efficacy after the completion of the VR/VX training also indicates that these professionals are ready to step into their practice setting with greater confidence and preparedness, which could lead to a

decrease in the rate of mistakes in the first few supervised experiences. For administrators in the healthcare industry, this equates to a more effective team of professionals able to accomplish complex tasks in the field of diagnostic imagery in a shorter timeframe in their overall career. It is important to note that these results provide a strong justification for the consideration of current VR/VX training methods to be given the same or even greater weight than the learning that occurs in the lectured component of traditional education.

9. Conclusion

This study showed that training based on VR/VX significantly outperforms traditional instructional techniques in the area of learning to operate a CT scan within medical education. On all tested dimensions, including immediate knowledge acquisition, procedural performance, long-term knowledge retention, learner satisfaction, engagement, self-efficacy, and overall preference, immersive training consistently yielded superior results with large effect sizes. These findings support the integration of VR/VX technologies into the healthcare training curriculum both as a complement to more traditional forms of instruction and, in certain contexts, as a viable alternative itself. However, at the same time, this within-subjects design did bring about the potential of carryover effects. Hence, future research needs to consider counterbalanced or between-subject designs, include large and diverse samples, and prolong follow-up assessment to test long-term retention and transfer to real clinical environments. The overall generalizability would be further strengthened if this line of inquiry could be expanded to other diagnostic imaging procedures, surgical skills, and interprofessional training contexts.

Technologically, the future of work can be directed towards the design of adaptive systems that can customize the scenario according to the ability level of the learner, use performance analytics delivered in a real-time fashion, and leverage haptic feedback to improve the realism of procedures. The future of work will also require the continuous collaboration of teachers, healthcare professionals, and technical experts to ensure that advancements in virtual reality technologies continue to be evidence-based, scalable, and feasible. Based on the current study, the use of virtual reality/VX technologies can revolutionize healthcare education.

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