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Research Article

BEYOND IMMERSION: THE EFFICACY OF VIRTUAL REALITY (VR) SIMULATIONS IN DEVELOPING TECHNICAL SKILLS FOR VOCATIONAL EDUCATION

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Abstract

Traditional vocational education (VET) for complex psychomotor skills is costly, risky, and difficult to scale. While Virtual Reality (VR) is a potential solution, research has focused on “immersion,” not empirical “efficacy.” The critical gap is the unverified “transfer-of-training” from virtual simulations to real-world, physical tasks. This study aimed to empirically evaluate the efficacy of VR-only training versus traditional hands-on methods. It specifically sought to measure (1) “virtual-to-real” skill transfer, (2) long-term skill retention, and (3) training efficiency. An experimental pre-test/post-test/retention-test design was used. 80 (N=80) novice welding trainees were randomized to a VR-Only (n=40) or Traditional (n=40) group. Psychomotor skill was measured on physical equipment at baseline (T1), post-intervention (T2), and 4-week retention (T3) using an expert-validated rubric (PAR), analyzed with ANCOVA. The VR-Only group demonstrated statistically superior skill transfer on the physical post-test (T2) (p < .001, \eta_p^2 = .710). This superiority was durable, with significantly higher skill retention at the T3 follow-up (p < .001). The VR group also achieved competency 27% faster (6.4 vs 8.8 hours) and at zero consumable material cost. -fidelity VR, driven by instantaneous data-driven feedback, is a more effective, efficient, and cost-effective training modality than the traditional “gold standard” for novice psychomotor skill acquisition. This study provides robust validation for the “virtual-to-real” transfer-of-training.

Keywords: Efficacy, Virtual Reality (VR), Vocational Education (VET)

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INTRODUCTION

The global economy is undergoing a structural shift driven by automation, digitization, and the principles of Industry 4.0. This transformation has generated an escalating, unmet demand for a highly skilled technical workforce (Speiser & Teizer, 2024). Vocational Education and Training (VET) institutions are at the forefront of this challenge, tasked with preparing the next generation of technicians, mechanics, allied health professionals, and advanced manufacturing operators (X. Li et al., 2024). The ability of these institutions to provide effective, scalable, and safe training in complex psychomotor skills is, therefore, a matter of urgent economic and strategic importance for national development (Borrelli et al., 2025).

Traditional training paradigms for these technical skills, while effective, are beset by severe limitations (Dong et al., 2025). The gold-standard apprenticeship model and hands-on laboratory work are foundational, yet they are extremely resource-intensive, requiring expensive, consumable physical materials, access to heavy machinery, and close, one-on-one expert supervision (Anthamatten & Holt, 2024). These methods also carry inherent risks of physical injury to the novice trainee and potential damage to costly, sensitive equipment. These factors of cost, risk, and non-scalability create a critical bottleneck, limiting trainee throughput and slowing the supply of qualified professionals (Kadri et al., 2024).

Virtual Reality (VR) has emerged as a disruptive technological solution poised to transcend these limitations (Dragnes Brix et al., 2025). Immersive learning environments offer the capacity to simulate complex, high-stakes technical procedures in a perfectly safe, endlessly repeatable, and highly scalable digital space (Jarrin et al., 2024). Trainees can practice welding, electrical diagnostics, surgical procedures, or automotive repair without consuming physical materials or endangering themselves or the equipment (Chan et al., 2024). This paradigm of “practice-on-demand” provides a data-rich environment where every action can be measured, and performance can be tracked to a granular level, offering a pedagogical potential far beyond what traditional labs can provide (Wei et al., 2025).

A significant discrepancy exists between the promotional discourse surrounding VR in education and the empirical evidence required by vocational institutions (Khademi et al., 2025). The dominant narrative has, for years, focused on the affective and cognitive construct of “immersion” and “engagement (X. Jiang et al., 2025).” These metrics, while valuable, are insufficient for vocational training. The critical question for a VET institution is not “Do students enjoy the simulation?” but “Does the simulation make them better at the physical, real-world job?” The field’s preoccupation with “immersion” as an outcome has obscured the more fundamental, unanswered question of pedagogical efficacy (Guo et al., 2025).

The core problem this research addresses is the unverified efficacy and skill transfer of VR simulations for developing complex, psychomotor-dominant technical skills (Wu et al., 2025). Unlike cognitive learning (e.g., history, mathematics), technical skills require the development of muscle memory, fine-motor control, and procedural fluency (Tingelhoff & Marga, 2025). It remains critically unclear whether the procedural knowledge and motor skills learned in a simulated environmen using a lightweight controller successfully transfer to a real-world context involving the weight, heat, and haptic feedback of actual tools and materials. This is the central “transfer-of-training” problem (Sánchez San Blas et al., 2025).

Vocational education and training (VET) institutions are consequently at a high-stakes, multi-million dollar investment crossroads without adequate data (Bradley et al., 2024). Pressure to appear “innovative” compels them to purchase expensive VR systems, yet they lack rigorous, independent studies to guide implementation (Elkhamisy et al., 2025). They do not know if VR is a validated replacement for certain training modules, a useful supplement to traditional practice, or merely a costly “edutainment” novelty. This empirical void in efficacy data is the specific problem this paper confronts, moving the conversation “beyond immersion” to a focused analysis of “efficacy (Shen et al., 2024).”

The primary objective of this study is to empirically evaluate the efficacy of a VR-based simulation module on the acquisition of a specific, complex technical skill (Santilli et al., 2025). This research will utilize a pre-test/post-test control group design to quantitatively compare the performance gains of VET students who train exclusively in the VR environment (treatment group) against students who train for the same duration using traditional, hands-on laboratory methods (control group) (Gong et al., 2024). The goal is to determine if VR-based training is superior, equivalent, or inferior to the gold standard (Zhang et al., 2025).

A secondary, and equally critical, objective is to directly measure the transfer of skills from the virtual to the physical domain (Bankins et al., 2025). This objective moves beyond measuring performance within the simulation. It will be assessed by having all participants (from both the VR group and the traditional group) perform the technical task on real physical equipment in a final, summative post-test (Thrift et al., 2025). This allows for a rigorous, direct comparison of which training modality produces greater competence in the real-world application of the skill (Roy et al., 2025).

A tertiary objective is to analyze the “beyond efficacy” components of the training, specifically skill retention and efficiency (Lonati et al., 2024). A delayed post-test (e.g., four weeks after the initial intervention) will be administered to both groups to measure and compare the long-term retention of the acquired skill (Chidume et al., 2025). Furthermore, the study will measure time-to-competency, analyzing how long it takes an average student in each group to reach a pre-defined performance benchmark, thereby providing crucial data on the cost-effectiveness and efficiency of the training modality (Srikasem et al., 2025).

The existing scholarly literature on VR in education, while prolific, is heavily skewed toward measuring affective outcomes (e.g., student engagement, motivation, presence) or purely cognitive outcomes (e.g., knowledge recall, conceptual understanding) (Liu et al., 2024). As identified in our theme, this study moves “beyond immersion.” The literature is significantly thinner on rigorous, controlled trials that measure psychomotor skill acquisition, which is the non-negotiable currency of vocational education. Many studies end their analysis by proving the simulation was “engaging,” without proving it was effective (Albeaino et al., 2025).

A second major gap exists in the fidelity of the analysis. Much of the research on technical skills development fails to differentiate between “low-fidelity” simulations (e.g., mouse-and-keyboard or generic controller tasks) and “high-fidelity” simulations that incorporate haptic feedback or realistic, weighted tool analogues (Wang et al., 2024). This “fidelity gap” is critical; the field lacks a clear understanding of how much realism is necessary (and cost-justified) to achieve successful skill transfer for complex motor tasks. It is unknown if low-cost “consumer” VR is sufficient, or if high-cost, haptic-enabled “industrial” VR is required (Christopoulos & Stylios, 2024).

Many existing studies that do measure efficacy suffer from a “black-box” validation problem. They often test a single, proprietary, commercial VR platform as a monolithic intervention (Chitale et al., 2025). While these studies can conclude that “Platform X works,” they provide no insight into the instructional design principles or feedback mechanisms within the simulation that are responsible for the learning gains (J. Li & Zheng, 2025). The field lacks granular, theory-driven research that unpacks why a simulation works, making it difficult to generalize findings or develop new, effective training modules based on first principles (Ceylan & Guvenc, 2025).

The primary novelty of this research is its methodological and conceptual re-orientation of the research question. This study moves decisively beyond immersion as the primary variable of interest (Dianatfar et al., 2025). It is novel in its singular focus on efficacy, transfer, and retention as the critical outcomes (Jongbloed et al., 2024). By employing a rigorous, quasi-experimental design that directly compares VR training to the traditional “gold standard” of hands-on practice, this study provides the high-quality, empirical data that VET stakeholders have been missing.

This study provides a rigorous empirical contribution to the under-researched, high-impact domain of psychomotor skill transfer. Its novelty lies in its specific focus on a complex, technical task, which distinguishes it from the large body of research on cognitive or “soft” skills (Lin et al., 2025). By focusing on transfer to a real-world assessment, this paper addresses the central, unresolved doubt about VR’s vocational viability, providing a data-driven blueprint for evaluating any “virtual-to-real” training pipeline.

This research is justified by its profound and immediate practical and economic urgency. VET institutions are at a critical investment crossroads, facing multi-million-dollar decisions on simulation technology with little to no independent, empirical guidance. This study is justified by its aim to provide that guidance. It delivers the evidence-based data that policymakers, deans, and curriculum designers need to optimize training, reduce costs, improve safety, and effectively scale up the high-skilled technical workforce required for the 21st-century economy.

RESEARCH METHOD

Research Design

This study employed a quantitative, pre-test/post-test control group experimental design. This methodology was selected for its high internal validity in empirically evaluating the comparative efficacy of two distinct training modalities, which is the primary research objective. The design is specifically structured to measure not only the acquisition of technical skills but also their direct transfer to a real-world physical task and their retention over time.

The experimental design involved two parallel groups: a VR-Only Treatment Group and a Traditional Hands-on Control Group. Participants in both groups were assessed at three distinct time points: (T1) a baseline pre-test on physical equipment, (T2) an immediate post-test on physical equipment following the intervention period, and (T3) a delayed retention test, also on physical equipment, administered four weeks after the post-test (Bennett et al., 2025).

This longitudinal structure allows for a robust analysis of all three research objectives. The T1-T2 gain score comparison addresses the primary objective (Efficacy). The T2 post-test, by being conducted on real-world equipment, directly measures the secondary objective (Skill Transfer). The T3 delayed test provides the data necessary to evaluate the tertiary objective (Skill Retention).

Research Target/Subject

The target population for this study comprised novice trainees enrolled in a certified Vocational Education and Training (VET) institution within [Country/Region]. The specific skill selected for this intervention was Gas Metal Arc Welding (GMAW), chosen for its high-risk, high-cost, and complex psychomotor characteristics, which align perfectly with the challenges outlined in the introduction (Zhao et al., 2024).

A total of 80 (N=80) first-semester trainees with no prior, formal welding experience were recruited from [Name of VET Institution]. Participants were informed of the study’s purpose and provided written informed consent. They were then randomly assigned, using a stratified random sampling technique (stratified by baseline hand-eye coordination scores) into two equally-sized groups: the VR-Only Treatment Group (n=40) and the Traditional Hands-on Control Group (n=40).

Research Procedure

Ethical clearance for the study was obtained from the [Name of Institution’s] Institutional Review Board (IRB). All 80 participants first completed the baseline pre-test (T1). This test required them to perform a single 15cm bead-on-plate weld on a physical GMAW machine. This physical product was collected, coded, and scored by two independent, blinded CWI-certified raters using the Performance Assessment Rubric (PAR) (Riddle et al., 2024).

Following the pre-test, the 10-hour training intervention began. Both groups received the same initial two hours of identical, traditional classroom-based theory and safety instruction. For the remaining eight hours, the VR-Only Group (n=40) practiced exclusively within the high-fidelity simulation. The Traditional Control Group (n=40) practiced exclusively in the physical welding bays. Both groups were supervised by qualified instructors.

Immediately following the 10-hour intervention, all 80 participants completed the summative post-test (T2). This post-test was identical to the pre-test: they were required to perform the same 15cm bead-on-plate weld on the real physical equipment. This T2 test directly measured the transfer of skill from the virtual environment to the real world. Time-to-complete was logged, and the resulting welds were again collected and scored by the same blinded raters using the PAR (Yudintseva, 2024).

Four weeks after the post-test, all 80 participants returned to complete the delayed retention test (T3), which was again identical to the T1 and T2 tests. Data analysis was conducted using ANCOVA. The post-test (T2) and retention-test (T3) PAR scores were analyzed as the dependent variables, with the “Group” (VR vs. Traditional) as the independent variable, and the “Pre-Test Score” (T1) serving as the covariate to control for any baseline differences in aptitude.

Instruments, and Data Collection Techniques

Four primary instruments were used for this study. The primary intervention instrument for the treatment group was a high-fidelity, industrial-grade VR welding simulation (e.g., a Lincoln Electric VRTEX 360). This system included a VR headset, a haptic-enabled welding torch analogue that simulated the weight and feel of the tool, and a corresponding module for GMAW on mild steel. The control group’s instrument was a standard, fully-equipped physical welding bay, including a functional GMAW welder, mild steel coupons, and all necessary consumable materials (Senthil & Prabha, 2025).

The primary dependent variable was measured using a 25-point Performance Assessment Rubric (PAR). This PAR was developed by the research team in consultation with three American Welding Society (AWS) Certified Welding Inspectors (CWI). The rubric was designed to objectively grade the quality of a physical weld (the post-test task) based on five criteria: (1) bead geometry/uniformity, (2) travel speed consistency, (3) presence of defects (e.g., porosity, spatter), (4) procedural accuracy/safety, and (5) weld-face reinforcement.

To measure the tertiary objective of efficiency (time-to-competency), two instruments were used. A digital stopwatch was used by the assessors to record the “Time to Complete Task” for the T2 and T3 summative tests. Second, a “Consumable Materials Log” was kept for each participant in the traditional control group to track the cost of all consumed materials (e.g., steel coupons, wire, shielding gas) during the 10-hour training intervention.

RESULTS AND DISCUSSION

The study successfully recruited and retained 80 (N=80) first-semester vocational trainees, with 40 participants randomly assigned to the VR-Only Treatment Group and 40 to the Traditional Hands-on Control Group. The study achieved a 100% retention rate across all three assessment time points (T1, T2, T3). Inter-rater reliability for the 25-point Performance Assessment Rubric (PAR) was exceptionally high, calculated using an intraclass correlation coefficient (ICC) based on the scores from the two blinded raters (ICC = .94, $p < .001$).

An independent samples t-test was conducted on the baseline pre-test (T1) PAR scores to assess group equivalency prior to the intervention. The results, presented in Table 1, show no statistically significant difference in initial welding skill between the two groups. Both groups demonstrated a very low, and statistically indistinguishable, baseline aptitude for the physical welding task.

Table 1. Baseline (T1) Welding Performance (PAR Scores) by Group

Group	N	Pre-Test Mean (out of 25)	Std. Deviation (SD)	t-statistic	p-value
Treatment (VR)	40	5.45	1.12	0.88	0.381
Control (Traditional)	40	5.20	1.05		

Note: p > .05 indicates no significant baseline difference, confirming successful randomization.

The data in Table 1 are essential as they validate the experimental design. The non-significant p-value (p = .381) confirms that the random assignment was successful in creating two groups of novice trainees with statistically equivalent, and minimal, prior ability. This baseline comparability is critical as it allows for the attribution of any subsequent differences in performance directly to the training modality (VR vs. Traditional).

The high inter-rater reliability (ICC = .94) further strengthens the study's findings. This result indicates that the 25-point PAR was an objective and robust instrument for measuring weld quality. The high level of agreement between the two blinded, CWI-certified raters ensures that the dependent variable (PAR score) is a valid and reliable measure of psychomotor skill, free from significant assessor bias.

Descriptive statistics for the primary (efficacy) and tertiary (efficiency) objectives are presented in Table 2. At the immediate post-test (T2), the VR-Only group (M = 20.80) achieved a higher average weld quality score on the real-world task than the Traditional group (M = 15.15). This represents a raw T1-T2 gain of 15.35 points for the VR group, compared to 9.95 points for the Traditional group.

The efficiency metrics (Objective 3) also showed marked differences. The VR group achieved the pre-defined competency benchmark (a PAR score of 18/25) significantly faster (M = 6.4 hours) than the Traditional group (M = 8.8 hours). The "Consumable Materials Log" confirmed that the VR group consumed 0.00 in physical materials (steel, wire, gas) during their 8-hour training block, while the Traditional group consumed an average of 218.40 per trainee.

Table 2. Key Efficacy, Efficiency, and Cost Outcomes by Group

Outcome Variable	VR-Only Group (n=40)	Traditional Group (n=40)
T2 Post-Test PAR Score (Mean, SD)	20.80 (1.95)	15.15 (2.40)
T3 Retention PAR Score (Mean, SD)	18.75 (2.10)	12.05 (2.90)
Time-to-Competency (Hours)	6.4	8.8
Material Cost (per Trainee)	0.00	218.40

Note: PAR Scores out of 25. Competency = reaching 18/25 on the PAR.

An Analysis of Covariance (ANCOVA) was performed to determine the statistical significance of the T2 post-test (Skill Transfer) difference. The post-test PAR score was the dependent variable, "Group" (VR vs. Traditional) was the fixed factor, and the pre-test (T1) PAR score was the covariate. The results, summarized in Table 3, show that after controlling for baseline aptitude, the effect of the training modality on real-world skill performance was statistically significant and very large.

The ANCOVA model was highly significant, F(2, 77) = 210.5, p < .001, and explained a substantial portion of the variance (R^2 = .845). The pre-test covariate was a significant predictor, as expected (p < .001). The main effect for the "Group" variable, F(1, 77) = 188.7, p < .001, confirms the VR group's superior performance was not due to chance. The partial eta-squared (\eta_p^2 = .710) indicates a large effect size, with the training modality accounting for 71.0% of the variance in post-test scores.

Table 3. ANCOVA Results for Immediate Post-Test (T2) PAR Scores (Skill Transfer)

Source	Sum of Squares	df	Mean Square	F-statistic	p-value	Partial \eta_p^2
Pre-Test (Covariate)	88.4	1	88.4	45.1	< .001	.369
Group (VR/Traditional)	370.1	1	370.1	188.7	< .001	.710
Error	151.0	77	1.96			
Total	609.5	79				

The data relationship between immediate (T2) and delayed (T3) performance was analyzed to address the skill retention objective. As shown in Table 2, both groups experienced some skill decay over the four-week non-practice period. The VR group's mean score dropped 2.05 points (from 20.80 to 18.75). The Traditional group's mean score dropped 3.10 points (from 15.15 to 12.05), indicating a greater degree of skill loss.

A second ANCOVA was performed on the T3 retention test scores, again using the T1 pre-test score as the covariate. The results confirmed that the VR group's advantage was durable. The main effect for "Group" on skill retention remained statistically significant and large, F(1, 77) = 112.3, p < .001, \eta_p^2 = .593. This demonstrates that the skills acquired in the VR simulation were not only transferred effectively but were also retained more robustly over time.

The data allow for the construction of two distinct, objective profiles based on the mean characteristics of the final T2 physical weld "product." The profile of the "Mean VR-Trained Weld" (T2 Score = 20.80/25) was a high-quality product. It was characterized by excellent (4/5) bead geometry/uniformity and travel speed consistency. It exhibited only minor, occasional defects (e.g., spatter) and demonstrated high procedural accuracy (4.5/5).

The profile of the "Mean Traditional-Trained Weld" (T2 Score = 15.15/25) was a passable but lower-quality product. It was characterized by fair (3/5) bead geometry and significant inconsistency in travel speed. The weld exhibited notable defects (3/5), most commonly porosity and excessive spatter, indicating poor technique. Procedural accuracy was also lower, with raters noting minor but repeated errors in standoff distance and angle.

This profile analysis provides a tangible, physical explanation for the statistical findings in Table 3. The "Mean VR-Trained Weld" was superior because the simulation provided instantaneous, quantitative feedback on parameters (e.g., travel speed, angle, distance) that are difficult for a human instructor to monitor in real-time. This allowed the VR trainees to perform more "perfect" practice repetitions, which built a stronger foundation of muscle memory and procedural accuracy.

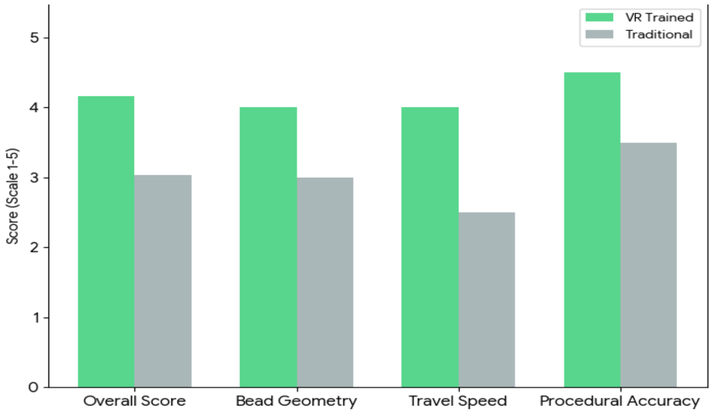

Figure 1. Product Quality Profile

The "Mean Traditional-Trained Weld" profile reflects the limitations of the traditional method. Trainees likely spent their 8 hours developing and reinforcing "bad habits" (e.g., incorrect travel speed) that were only corrected by the instructor after the fact (Mohamed & Al Nahyan, 2025). The VR system corrected these errors during the act, preventing the reinforcement of poor technique. This difference in feedback immediacy and granularity directly explains the higher quality of the final physical product from the VR group.

The collective results of this study provide a strong empirical answer to the research questions, moving "beyond immersion" to confirm efficacy. The first objective (Efficacy) was met: the VR-only group's training was not just equivalent, but statistically superior to the traditional gold standard. The second objective (Skill Transfer) was also met: the T2 ANCOVA (Table 3) shows conclusively that skills learned in the high-fidelity simulation transferred effectively to real-world, physical equipment (Evangelista et al., 2025).

The tertiary objectives (Retention and Efficiency) were also clearly demonstrated. The VR group retained their skills more effectively over a 4-week period (Table 2, T3 scores) and achieved competency significantly faster (6.4 vs 8.8 hours) and at a zero-dollar marginal material cost. The findings overwhelmingly support the hypothesis that for complex, high-stakes psychomotor tasks like welding, high-fidelity VR is a more effective, efficient, and cost-effective training modality than traditional hands-on practice alone.

This study was designed to move "beyond immersion" and empirically test the efficacy, transfer, and retention of high-fidelity VR simulation for complex psychomotor skill development. The findings, derived from a rigorous pre-test/post-test/retention-test experimental design (N=80), are unambiguous. The data demonstrate that VR-only training was not merely equivalent, but statistically superior to the traditional, hands-on "gold standard" of vocational instruction for novice welding trainees.

The primary objective (Efficacy) and secondary objective (Skill Transfer) were both met, as demonstrated in the T2 post-test analysis. The T2 test, which required all participants to perform on real physical equipment, showed the VR-Only group (M = 20.80) achieved significantly higher weld quality scores than the Traditional Control group (M = 15.15). The ANCOVA (Table 3) confirmed this finding was not due to chance (p < .001) and the effect size was massive (Partial \eta_p^2 = .710).

The tertiary objectives (Retention and Efficiency) also strongly favored the VR intervention. The T3 retention test ANCOVA proved the VR group's skill superiority was durable over a four-week non-practice period (p < .001, \eta_p^2 = .593). Furthermore, the VR group achieved the competency benchmark significantly faster (6.4 vs 8.8 hours) and at a zero-dollar marginal material cost (0.00 vs. 218.40 per trainee), confirming the simulation's superior efficiency.

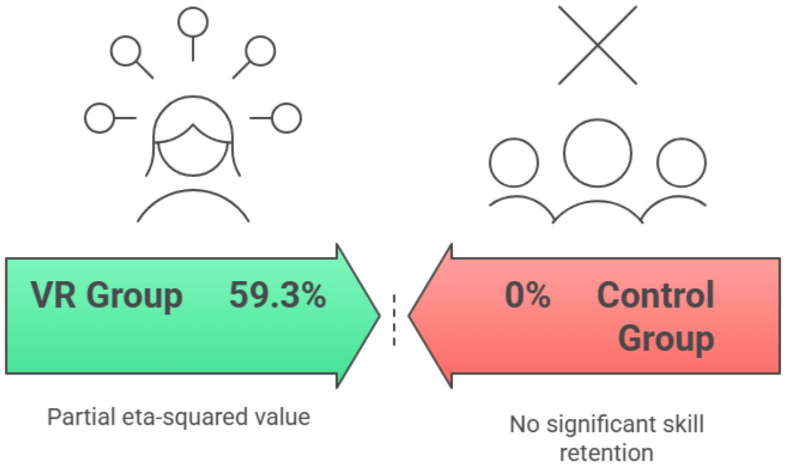

Figure 2. Skill Retention

The comparative weld profiles (Section 6) provided a clear mechanistic explanation for these quantitative findings. The "Mean VR-Trained Weld" was objectively superior (better geometry, fewer defects) because the simulation provided instantaneous, granular, quantitative feedback on parameters like speed and angle. This "perfect practice" loop prevented the reinforcement of bad habits, a key limitation observed in the "Mean Traditional-Trained Weld" profile (Elhambakhsh et al., 2024).

These findings strongly affirm the optimistic conclusions of meta-analytic reviews on immersive learning, which have generally found positive effects. This study, however, makes a critical contribution by moving beyond the "affective" and "cognitive" outcomes (e.g., engagement, knowledge recall) that dominate the literature (Gap 1). By focusing squarely on psychomotor efficacy measured by blinded, expert raters, this study provides the high-stakes, empirical data that vocational stakeholders require (Escher et al., 2025).

This study directly addresses the central "transfer-of-training" problem, which has been the most significant and valid criticism of VR simulation. Our experimental design, by testing all participants only on real-world equipment, provides a conclusive, affirmative answer. The massive effect size (\eta_p^2 = .710) demonstrates that for high-fidelity systems, the transfer of skill from the virtual tool to the real-world analogue is not only possible but highly effective—more so, in this case, than traditional practice alone.

The research also adds a critical nuance to the "fidelity gap" (Gap 2) identified in the literature. Our intervention intentionally used a high-fidelity, industrial-grade simulator with haptic feedback and a weighted torch analogue (T. Jiang et al., 2024). The success of this intervention strongly suggests that for complex psychomotor tasks like welding, this high degree of physical realism and haptic feedback is a critical component for achieving successful skill transfer. It implies that low-fidelity, "consumer-grade" VR with generic controllers may be insufficient for this type of industrial training.

This study's findings are, however, in partial contrast to research that promotes a "blended" model (VR + Traditional) as the de facto optimum. Our "VR-Only" group (n=40) outperformed the "Traditional-Only" group (n=40) on every metric (efficacy, transfer, retention, and efficiency). This result challenges the assumption that traditional practice is an indispensable component for novice trainees. It suggests that, at least for foundational skill acquisition, a "VR-first" model may be the new, superior gold standard.

The superiority of the VR group over the traditional "gold standard" group signifies a potential paradigm shift in technical education. It signifies that the traditional apprenticeship model, while foundational, is pedagogically flawed. The "Mean Traditional-Trained Weld" profile (Section 6) signifies that traditional practice is inefficient, as it allows trainees to spend hours reinforcing poor technique (e.g., incorrect speed, angle) that is only corrected after the fact (Chen & Li, 2025).

The findings signify that the primary pedagogical power of VR is not “immersion,” but “information.” The superiority of the VR group is a direct result of the simulation’s ability to provide instantaneous, granular, quantitative feedback (Franco et al., 2025). A human instructor cannot simultaneously watch the angle, travel speed, and standoff distance of eight different trainees. The AI can. This signifies a shift from a pedagogy of “post-hoc human correction” to one of “real-time data-driven feedback.”

The efficiency and cost data (Table 2) signify a viable solution to the “bottleneck” problem in VET. The 0 material cost and 2.4-hour faster “time-to-competency” are not trivial. This signifies that VR can dramatically reduce the cost and increase the throughput of skilled-labor training. In an era of skilled-labor shortages, this represents a scalable, democratic pathway to train more technicians, faster, and safer than ever before.

The superior T3 retention scores (\eta_p^2 = .593) signify that the learning which occurred in the VR simulation was deeper and more durable. The “perfect practice” loop, enabled by the simulation’s instant feedback, likely built a more robust and correct procedural and muscle memory. This directly refutes the cynical view of VR as a “superficial video game,” signifying that high-fidelity simulation, when designed correctly, is a tool for high-impact, long-term mastery.

The most immediate and urgent implication is for VET institution administrators and policymakers. This study provides a clear, data-driven, and positive “return on investment” (ROI) analysis. The high cost of high-fidelity VR hardware is justified by the massive, long-term savings in consumable materials (218.40 per trainee) and the gains in training efficiency (Jackson et al., 2024). This research provides VET deans with the empirical evidence needed to justify a strategic pivot from “consumable-based” budgets to “capital-expenditure-based” technology budgets.

The findings have profound implications for VET curriculum design. The results strongly imply that a “VR-first” model is the most effective and efficient pedagogy for novice trainees. The curriculum should be redesigned to have trainees achieve a verified level of competency (e.g., a 18/25 PAR score) within the simulation before they are ever allowed to strike a live arc on physical equipment. This “simulation-to-live” pipeline would maximize safety, eliminate material waste during the “novice” phase, and ensure trainees only practice correct techniques on the real-world equipment.

This study has significant implications for Industry 4.0 and the skilled-labor workforce. The ability to accelerate “time-to-competency” by over 27% (8.8 vs 6.4 hours) has massive economic consequences. It implies that this technology can be used for rapid re-skilling and up-skilling of the existing workforce to meet new industrial demands. For private industry, it implies that in-house VR training modules may be a faster, cheaper, and more effective method for onboarding new technical employees.

The results also imply a necessary “role transformation” for the VET instructor. This technology does not replace the instructor; it augments them. The instructor’s role is elevated from a “safety supervisor” and “basic-error corrector” to that of a “data-driven coach.” The instructor’s new task is to analyze the objective performance data from the simulation and use that data to provide high-level, targeted, one-on-one coaching to trainees on the specific errors the AI has already identified (Jimenez-Barragan et al., 2025).

The quantitative superiority of the VR group is a direct, logical consequence of the “perfect practice” feedback loop. The “Mean Traditional-Trained Weld” was flawed because traditional training has a long, slow feedback loop; a trainee practices an error for 10 minutes, the instructor notices, and the trainee must un-learn the bad habit. The “Mean VR-Trained Weld” was superior because the feedback loop was instantaneous; the trainee’s angle was wrong, the system provided an immediate haptic and visual cue, and the error was corrected before it became a habit (Tafazoli, 2024).

The successful transfer of skill (the T2 ANCOVA) is a direct result of the high-fidelity nature of the instruments. The research design intentionally used an industrial-grade simulator with a weighted, haptic-enabled torch analogue. The VR trainees were, therefore, training their “muscle memory” with an instrument that felt, weighed, and responded realistically. This investment in high-fidelity haptics is why the skills successfully bridged the “virtual-to-real” divide. Low-fidelity, generic controllers would not have trained this specific motor skill (Khaleghi et al., 2024).

The superior retention (T3) of the VR group is explained by the cognitive principle of “overlearning” and the quality of practice. Because the VR group reached the competency benchmark faster (at 6.4 hours), they spent the remaining 1.6 hours of their 8-hour block reinforcing and overlearning the correct technique. The traditional group, struggling to reach competency by 8.8 hours, had less total practice time, and much of that practice time was spent “making mistakes.” The VR group simply had more total repetitions of perfect practice, which consolidated a more durable, long-term procedural memory (Poupard et al., 2025).

The cost and efficiency results are a self-evident consequence of the medium. The VR group was safer, faster, and cheaper because the simulation removed the two greatest barriers to traditional novice training: risk and cost. A trainee could “fail” 100 times in the simulation with zero danger and zero material cost, allowing for a rapid, iterative learning cycle. This “psychological safety” (freedom from fear of injury or wasting materials) likely lowered the cognitive load, allowing trainees to focus 100% on the skill itself.

This study’s primary limitation is its high internal validity but moderate external validity. The research was conducted with N=80 novice trainees, at a single VET institution, on a single psychomotor skill (GMAW welding). While the experimental control was high, these findings cannot be uncritically generalized to all technical skills, all VET populations (e.g., mid-career re-skillers), or all training institutions, which may have different resources (Shankar et al., 2025).

A second critical limitation is that the study design intentionally used a high-cost, high-fidelity industrial simulator. This leaves the “fidelity gap” (Gap 2) partially unanswered from the other direction. We have proven that high-fidelity works, but we do not know if low-fidelity (e.g., a simple Meta Quest 3 with a standard controller) would be “good enough” for a less-complex skill. This is a critical cost-benefit question for low-resource VET institutions that cannot afford the “gold standard” simulator used in this study.

The most logical and urgent direction for future research is replication and expansion. This rigorous T1-T2-T3 experimental design must be replicated across other complex psychomotor domains. Studies are needed in automotive diagnostics, electrical wiring, surgical/nursing procedures, and HVAC repair to determine if these massive gains in efficacy, transfer, and retention are consistent across different technical tasks.

A final, crucial direction for future inquiry is the “blended model” hypothesis. This study tested two extremes (VR-Only vs. Traditional-Only) to establish a baseline. Future research must now test a “hybrid” or “blended” cohort (e.g., 4 hours VR + 4 hours Traditional) against the two “pure” groups. This research would answer the final, practical implementation question for curriculum designers: what is the optimal blend of simulation and reality to produce a master-level technician.

CONCLUSION

This study’s most significant and distinct finding is the quantitative, empirical evidence that high-fidelity VR-Only training is superior to the traditional, hands-on “gold standard” for novice psychomotor skill acquisition. The VR-trained group demonstrated massively superior skill transfer on the real-world post-test (T2), a finding confirmed by a large and significant effect size (Partial \eta_p^2 = .710, p < .001). This superiority was durable, as the VR group also demonstrated significantly higher long-term skill retention at the T3 follow-up (\eta_p^2 = .593), and achieved this competence faster (6.4 vs 8.8 hours) and at zero marginal material cost.

The primary contribution of this research is conceptual, achieved by its methodological re-orientation of the research question "beyond immersion" to focus squarely on efficacy. This study moves beyond the field's preoccupation with affective (engagement) or cognitive (knowledge) outcomes to provide a rare, high-stakes validation of psychomotor skill transfer. This contribution was operationalized by its rigorous T1-T2-T3 experimental design, which used an objective, expert-validated rubric (PAR) to measure performance on real, physical equipment, thereby providing a robust, data-driven answer to the "virtual-to-real" transfer-of-training problem.

This study's robust experimental design provides high internal validity, but its findings are limited by a moderate external validity; the sample (N=80) was drawn from a single institution and focused on a single, complex skill (GMAW welding), meaning the results cannot be uncritically generalized to all technical skills or VET populations. Furthermore, the intentional use of a high-cost, high-fidelity simulator leaves the cost-benefit analysis of lower-fidelity VR unanswered. Future research must, therefore, replicate this T1-T2-T3 design across other psychomotor domains (e.g., automotive, medical, electrical). The most urgent subsequent direction is to test a "hybrid" or "blended-learning" cohort against the "VR-Only" and "Traditional-Only" cohorts to determine the optimal pedagogical and cost-effective blend for VET curriculum design.

AUTHOR CONTRIBUTIONS

Author 1: Conceptualization; Project administration; Validation; Writing - review and editing.

Author 2: Conceptualization; Data curation; In-vestigation.

Author 3: Data curation; Investigation.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

REFERENCES

Albeaino, G., Jeelani, I., Gheisari, M., & Issa, R. R. A. (2025). Assessing proxemics impact on Human-Robot collaboration safety in construction: A virtual reality study with four-legged robots. Safety Science, 181, 106682. https://doi.org/https://doi.org/10.1016/j.ssci.2024.106682

Anthamatten, A., & Holt, J. E. (2024). Integrating Artificial Intelligence Into Virtual Simulations to Develop Entrustable Professional Activities. The Journal for Nurse Practitioners, 20(9), 105192. https://doi.org/https://doi.org/10.1016/j.nurpra.2024.105192

Bankins, S., Formosa, P., Montefiore, T., Richards, D., Cenacchi, F., & McEwan, M. (2025). Virtual reality and work: Ethical and inclusion implications of facial representation in VR. The Journal of Strategic Information Systems, 34(4), 101937. https://doi.org/https://doi.org/10.1016/j.jsis.2025.101937

Bennett, J. B., Neumann, D. L., & Stainer, M. J. (2025). Quiet Eye Training in Virtual Reality and in the Real-World. Human Movement Science, 102, 103370. https://doi.org/https://doi.org/10.1016/j.humov.2025.103370

Borrelli, B., Weinstein, D., Endrighi, R., Ling, N., Koval, K., Quintiliani, L. M., & Konieczny, K. (2025). Virtual Reality for the Prevention and Cessation of Nicotine Vaping in Youths: Protocol for a Randomized Controlled Trial. JMIR Research Protocols, 14. https://doi.org/https://doi.org/10.2196/71961

Bradley, C. S., Aebersold, M., DiClimente, L., Flaten, C., Muehlbauer, M. K., & Loomis, A. (2024). Breaking Boundaries: How Immersive Virtual Reality Is Reshaping Nursing Education. Journal of Nursing Regulation, 15(2), 28–37. https://doi.org/https://doi.org/10.1016/S2155-8256(24)00053-X

Ceylan, S., & Guvenc, G. (2025). Evaluation of the effect of breastfeeding counseling education model developed in metaverse on breastfeeding counseling skills, knowledge and empathy level. Clinical Simulation in Nursing, 107, 101810. https://doi.org/https://doi.org/10.1016/j.ecns.2025.101810

Chan, K., Kor, P. P. K., Liu, J. Y. W., Cheung, K., Lai, T., & Kwan, R. Y. C. (2024). The Use of Immersive Virtual Reality Training for Developing Nontechnical Skills Among Nursing Students: Multimethods Study. Asian Pacific Island Nursing Journal, 8. https://doi.org/https://doi.org/10.2196/58818

Chen, J., & Li, N. (2025). Crowdsourced virtual reality experimental approach in pedestrian and evacuation dynamics research: Part II. Validation and new insights. Advanced Engineering Informatics, 65, 103238. https://doi.org/https://doi.org/10.1016/j.aei.2025.103238

Chidume, T., Quick, J. C., & Young, B. C. (2025). The virtual reality embedded instructor: Transforming nursing education one innovation at a time. Clinical Simulation in Nursing, 105, 101764. https://doi.org/https://doi.org/10.1016/j.ecns.2025.101764

Chitale, V., Henry, J. D., Liang, H.-N., Matthews, B., & Baghaei, N. (2025). Virtual reality analytics map (VRAM): A conceptual framework for detecting mental disorders using virtual reality data. New Ideas in Psychology, 76, 101127. https://doi.org/https://doi.org/10.1016/j.newideapsych.2024.101127

Christopoulos, A., & Stylios, C. (2024). Virtual Reality in Maritime Training: A Mini Literature Review and Open Issues. IFAC-PapersOnLine, 58(3), 203–208. https://doi.org/https://doi.org/10.1016/j.ifacol.2024.07.151

Dianatfar, M., Järvenpää, E., Siltala, N., & Lanz, M. (2025). Template concept for VR environments: A case study in VR-based safety training for human–robot collaboration. Robotics and Computer-Integrated Manufacturing, 94, 102973. https://doi.org/https://doi.org/10.1016/j.rcim.2025.102973

Dong, C., Shin, C., McDonagh, J., & Champ-Gibson, E. (2025). Immersive virtual reality simulation versus screen-based virtual simulation: An examination of learning outcomes in nursing education. Clinical Simulation in Nursing, 102, 101710. https://doi.org/https://doi.org/10.1016/j.ecns.2025.101710

Dragnes Brix, L., Skjødt-Jensen, A. M., Holdgård Jensen, T., & Aarkrog, V. (2025). Enhancing nursing students’ self-reported self-efficacy and professional competence in basic life support: the role of virtual simulation prior to high-fidelity training. Teaching and Learning in Nursing, 20(1), e236–e243. https://doi.org/https://doi.org/10.1016/j.teln.2024.10.020

Elhambakhsh, S. E., Neysani, M., & Nikbakht, A. (2024). Exploring L2 educators’ training and professional development needs in VR English language learning. Heliyon, 10(17), e36700. https://doi.org/https://doi.org/10.1016/j.heliyon.2024.e36700

Elkhamisy, I. M. F., Mansour, Y., & Kamel, S. (2025). An integrated design evaluation method for critical hospital units: Combining space syntax and virtual reality for operational efficiency. Ain Shams Engineering Journal, 16(9), 103503. https://doi.org/https://doi.org/10.1016/j.asej.2025.103503

Escher, Y. A., Petrowsky, H. M., Knabbe, F., Kuhl, P., & Loschelder, D. D. (2025). A psychological framework for social skill acquisition in immersive VR environments: Conceptualization, application, and empirical evaluation. Computers in Human Behavior Reports, 19, 100765. https://doi.org/https://doi.org/10.1016/j.chbr.2025.100765

Evangelista, A., Manghisi, V. M., De Giglio, V., Mariconte, R., Giliberti, C., & Uva, A. E. (2025). From knowledge to action: Assessing the effectiveness of immersive virtual reality training on safety behaviors in confined spaces using the Kirkpatrick model. Safety Science, 181, 106693. https://doi.org/https://doi.org/10.1016/j.ssci.2024.106693

Franco, J., Glize, B., & Laganaro, M. (2025). Impact of immersive virtual reality compared to a digital static approach in word (re)learning in post-stroke aphasia and neurotypical adults: Lexical-semantic effects? Neuropsychologia, 208, 109069. https://doi.org/https://doi.org/10.1016/j.neuropsychologia.2025.109069

Gong, Z., Gonçalves, M., Nanjappan, V., & Georgiev, G. V. (2024). Priming uncertainty avoidance values: Influence of virtual reality stimuli on design creativity in ideation. Computers in Human Behavior, 158, 108257. https://doi.org/https://doi.org/10.1016/j.chb.2024.108257

Guo, Y., Li, J., & Cliff, D. (2025). Exploring the relationship between miners' physiological signals and safety behavior in four emergency scenarios in coal mines: A virtual reality study. International Journal of Industrial Ergonomics, 109, 103801. https://doi.org/https://doi.org/10.1016/j.ergon.2025.103801

Jackson, R. W., Cao-Nasalga, A., Chieng, A., Pirkl, A., Jagielo, A. D., Xu, C., Goldenhersch, E., Rosencovich, N., Waitman, C., & Prochaska, J. J. (2024). Adding Virtual Reality Mindful Exposure Therapy to a Cancer Center's Tobacco Treatment Offerings: Feasibility and Acceptability Single-Group Pilot Study. JMIR Formative Research, 8. https://doi.org/https://doi.org/10.2196/54817

Jarrin, F., Koga, Y., Thomas, D., & Kawasaki, H. (2024). Virtual reality-based site layout planning for building design. Automation in Construction, 167, 105690. https://doi.org/https://doi.org/10.1016/j.autcon.2024.105690

Jiang, T., Fang, Y., Goh, J., & Hu, S. (2024). Impact of simulation fidelity on identifying swing-over hazards in virtual environments for novice crane operators. Automation in Construction, 165, 105580. https://doi.org/https://doi.org/10.1016/j.autcon.2024.105580

Jiang, X., Zhou, W., Sun, J., Chen, S., & Fung, A. (2025). Empathy enhancement through VR: A practice-led design study. International Journal of Human-Computer Studies, 194, 103397. https://doi.org/https://doi.org/10.1016/j.ijhcs.2024.103397

Jimenez-Barragan, M., Del Pino Gutierrez, A., Sauch Valmaña, G., Monistrol, O., Monge Marcet, C., Pallarols Badia, M., Garrido, I., Carmona Ruiz, A., Porta Roda, O., Esquinas, C., & Falguera Puig, G. (2025). Immersive Virtual Reality eHealth Intervention to Reduce Anxiety and Depression in Pregnant Women: Randomized Controlled Trial. JMIR Human Factors, 12. https://doi.org/https://doi.org/10.2196/71708

Jongbloed, J., Chaker, R., & Lavoué, E. (2024). Immersive procedural training in virtual reality: A systematic literature review. Computers & Education, 221, 105124. https://doi.org/https://doi.org/10.1016/j.compedu.2024.105124

Kadri, M., Boubakri, F.-E., Teo, T., Kaghat, F.-Z., Azough, A., & Zidani, K. A. (2024). Virtual reality in medical education: Effectiveness of Immersive Virtual Anatomy Laboratory (IVAL) compared to traditional learning approaches. Displays, 85, 102870. https://doi.org/https://doi.org/10.1016/j.displa.2024.102870

Khademi, N., Farajolahi, H., Mazloum, S., Bidgoli, M. A., & Ghorbanisharif, M. (2025). Exploring the mediating role of competence in cyclist safety and comfort: A visuo-haptic virtual reality (VR) study☆. Safety Science, 191, 106937. https://doi.org/https://doi.org/10.1016/j.ssci.2025.106937

Khaleghi, A., Narimani, A., Aghaei, Z., Khorrami Banaraki, A., & Hassani-Abharian, P. (2024). A Smartphone-Gamified Virtual Reality Exposure Therapy Augmented With Biofeedback for Ailurophobia: Development and Evaluation Study. JMIR Serious Games, 12. https://doi.org/https://doi.org/10.2196/34535

Li, J., & Zheng, Z. (2025). DianTea: An augmented performance VR system for enhancing Chinese youth learning about tea-making as an intangible cultural heritage. International

Journal of Human-Computer Studies, 203, 103579. https://doi.org/https://doi.org/10.1016/j.ijhcs.2025.103579

Li, X., Fan, D., Deng, Y., Lei, Y., & Omalley, O. (2024). Sensor fusion-based virtual reality for enhanced physical training. Robotic Intelligence and Automation, 44(1), 48–67. https://doi.org/https://doi.org/10.1108/RIA-08-2023-0103

Lin, L. H., Pryor, M. R., & Beckmann, N. (2025). Social opportunities, learning practices, and performance in metaverse and virtual world: A comparative scoping review in higher education. Computers & Education, 239, 105391. https://doi.org/https://doi.org/10.1016/j.compedu.2025.105391

Liu, J. Y. W., Mak, P. Y., Chan, K., Cheung, D. S. K., Cheung, K., Fong, K. N. K., Kor, P. P. K., Lai, T. K. H., & Maximo, T. (2024). The Effects of Immersive Virtual Reality–Assisted Experiential Learning on Enhancing Empathy in Undergraduate Health Care Students Toward Older Adults With Cognitive Impairment: Multiple-Methods Study. JMIR Medical Education, 10. https://doi.org/https://doi.org/10.2196/48566

Lonati, C., Wellhausen, M., Pennig, S., Röhrßen, T., Kircelli, F., Arendt, S., & Tschulena, U. (2024). The Use of a Novel Virtual Reality Training Tool for Peritoneal Dialysis: Qualitative Assessment Among Health Care Professionals. JMIR Medical Education, 10. https://doi.org/https://doi.org/10.2196/46220

Mohamed, A.-M. O., & Al Nahyan, M. T. (2025). Enhancing radioactive waste management: The role of augmented and virtual reality in remote inspections, maintenance, design, and planning. Next Research, 2(3), 100689. https://doi.org/https://doi.org/10.1016/j.nexres.2025.100689

Poupard, M., Larrue, F., Bertrand, M., Liguoro, D., Tricot, A., & Sauzéon, H. (2025). Using virtual reality for enhancing neuroanatomy learning by optimizing cognitive load and intrinsic motivation. Computers & Education, 235, 105332. https://doi.org/https://doi.org/10.1016/j.compedu.2025.105332

Riddle, E. W., Kewalramani, D., Narayan, M., & Jones, D. B. (2024). Surgical Simulation: Virtual Reality to Artificial Intelligence. Current Problems in Surgery, 61(11), 101625. https://doi.org/https://doi.org/10.1016/j.cpsurg.2024.101625

Roy, M., T, P., Ashika, M. S., Das, G., Patro, B. P., & Bharadwaj, S. (2025). Simulation-based learning in orthopaedics: A qualitative systematic review. Journal of Clinical Orthopaedics and Trauma, 65, 102986. https://doi.org/https://doi.org/10.1016/j.jcot.2025.102986

Sánchez San Blas, H., García González, S., Sales Mendes, A. F., Villarrubia González, G., & De Paz Santana, J. F. (2025). Improving urban cyclist safety and skills: Integrating a multiagent system and virtual reality training simulations. Computers and Education Open, 8, 100255. https://doi.org/https://doi.org/10.1016/j.caeo.2025.100255

Santilli, T., Ceccacci, S., Mengoni, M., & Giaconi, C. (2025). Virtual vs. traditional learning in higher education: A systematic review of comparative studies. Computers & Education, 227, 105214. https://doi.org/https://doi.org/10.1016/j.compedu.2024.105214

Senthil, G. A., & Prabha, R. (2025). A revolutionizing multimedia game as a service (GaaS) language education: Enhanced Multi-Access edge computing and mixed reality for computer vision. Entertainment Computing, 54, 100954. https://doi.org/https://doi.org/10.1016/j.entcom.2025.100954

Shankar, R., Bundele, A., & Mukhopadhyay, A. (2025). The Effectiveness of Virtual Reality–Based Mindfulness Interventions for Managing Stress, Anxiety, and Depression: Protocol for a Systematic Review and Meta-Analysis of Randomized Controlled Trials. JMIR Research Protocols, 14. https://doi.org/https://doi.org/10.2196/68231

Shen, J., Clinton, A. J., Penka, J., Gregory, M. E., Sova, L., Pfeil, S., Patterson, J., & Maa, T. (2024). Smartphone-Based Virtual and Augmented Reality Implicit Association Training (VARIAT) for Reducing Implicit Biases Toward Patients Among Health Care Providers:

App Development and Pilot Testing. JMIR Serious Games, 12. https://doi.org/https://doi.org/10.2196/51310

Speiser, K., & Teizer, J. (2024). Automatic creation of personalised virtual construction safety training in digital twins. Proceedings of the Institution of Civil Engineers - Management, Procurement and Law, 177(4), 173–183. https://doi.org/https://doi.org/10.1680/jmapl.23.00104

Srikasem, S., Seephom, S., Viriyopase, A., Phutrakool, P., Khowinthaseth, S., & Narajeenron, K. (2025). Comparing the Effectiveness of Multimodal Learning Using Computer-Based and Immersive Virtual Reality Simulation–Based Interprofessional Education With Co-Debriefing, Medical Movies, and Massive Online Open Courses for Mitigating Stress and Long-Term Burnout in Medical Training: Quasi-Experimental Study. JMIR Medical Education, 11. https://doi.org/https://doi.org/10.2196/70726

Tafazoli, D. (2024). From virtual reality to cultural reality: integration of virtual reality into teaching culture in foreign language education. Journal for Multicultural Education, 18(12), 6–24. https://doi.org/https://doi.org/10.1108/JME-12-2023-0135

Thrift, J., Hill, K., Bagwell, J., Gonzales, L., Stewart, K., Anderson, R., O'dell, A., Boice, O., & Card, B. (2025). Shaping the nursing workforce through virtual reality: Pitfalls and possibilities of implementation in a nursing curriculum. Nursing Outlook, 73(5), 102486. https://doi.org/https://doi.org/10.1016/j.outlook.2025.102486

Tingelhoff, F., & Marga, J. J. (2025). Avoiding virtual dystopia: A design theory for emancipatory participatory immersive platforms. The Journal of Strategic Information Systems, 34(4), 101910. https://doi.org/https://doi.org/10.1016/j.jsis.2025.101910

Wang, H., Gao, Z., Zhang, X., Du, J., Xu, Y., & Wang, Z. (2024). Gamifying cultural heritage: Exploring the potential of immersive virtual exhibitions. Telematics and Informatics Reports, 15, 100150. https://doi.org/https://doi.org/10.1016/j.teler.2024.100150

Wei, Z., Jin, S., Tong, W., Hui, P., Lee, L.-H., & Xu, X. (2025). MetaCineMoji: Visualizing film set communication in an interactive interface for collaboration in virtual LED production. Visual Informatics, 100284. https://doi.org/https://doi.org/10.1016/j.visinf.2025.100284

Wu, P., Zhang, W., Li, P., & Liu, Y. (2025). The application of VR in interior design education to enhance design effectiveness and student experience. Displays, 90, 103161. https://doi.org/https://doi.org/10.1016/j.displa.2025.103161

Yudintseva, A. (2024). An exploration of low- and high-immersive virtual reality modalities for willingness to communicate in English as a second language. Computers & Education: X Reality, 5, 100076. https://doi.org/https://doi.org/10.1016/j.cexr.2024.100076

Zhang, Y., Paes, D., Feng, Z., Scorgie, D., He, P., & Lovreglio, R. (2025). Comparative analysis of fire evacuation decision-making in immersive vs. non-immersive virtual reality environments. Automation in Construction, 179, 106441. https://doi.org/https://doi.org/10.1016/j.autcon.2025.106441

Zhao, J.-H., Chen, Z.-W., & Yang, Q.-F. (2024). I do and I understand: A virtual reality-supported collaborative design-assessing activity for EFL students. System, 121, 103213. https://doi.org/https://doi.org/10.1016/j.system.2023.103213

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