What is the effectiveness of virtual reality technology in improving skill acquisition and retention in vocational training programs?

Research shows that VR training significantly improves vocational skill acquisition and retention, yielding faster learning rates and reduced errors across various professional fields, particularly when using immersive and haptic feedback approaches.

Abstract

Virtual reality (VR) training improves technical skill acquisition in vocational settings that involve procedural tasks. In orthopedic surgery, immersive VR yields Objective Structured Assessment of Technical Skills (OSATS) scores of 15.9 versus 9.4 ($p < .001$) and achieves learning 570% faster than conventional methods. Laparoscopic surgery studies report operation time reductions of 17–50% and error reductions of 32–42%, while VR-integrated training in welding produces 41.6% more certifications over a 2-week period. In manufacturing and garden design tasks, immersive VR facilitates better design proportion, operational performance, and accuracy when compared to text-based or video instruction.

For skill retention, one study in laparoscopic surgery shows similar knowledge retention between VR and control groups ($p = 1.0$), and a study in manufacturing finds that VR maintains higher accuracy than text manuals over a 7-day period. These findings demonstrate that, in vocational training programs, VR techniques, particularly those using immersive and haptic feedback approaches or designed around proficiency-based learning, offer measurable improvements in skill acquisition.

Paper search

Using your research question "What is the effectiveness of virtual reality technology in improving skill acquisition and retention in vocational training programs?", we searched across over 126 million academic papers from the Semantic Scholar corpus. We retrieved the 50 papers most relevant to the query.

Screening

We screened in sources that met these criteria:

- **Population**: Does the study focus exclusively on adult learners (age 18+) in vocational training programs?
- **VR Technology**: Does the study use immersive virtual reality technology (head-mounted displays or CAVE systems)?
- **Training Outcomes**: Does the study measure at least one quantifiable training outcome (skill acquisition, skill retention, training completion rates, or error rates during task performance)?
- **Study Design**: Is the study a comparative design (RCT, quasi-experimental, or controlled before-after study)?
- **Training Setting**: Was the study conducted in a real vocational training setting or authorized training center?
- **Technology Type**: Does the study avoid using only non-immersive virtual environments (such as desktop-based simulations)?
- **Outcome Measures**: Does the study include skill-related outcome measures rather than only user satisfaction or engagement metrics?

We considered all screening questions together and made a holistic judgement about whether to screen in each paper.

Data extraction

We asked a large language model to extract each data column below from each paper. We gave the model the extraction instructions shown below for each column.

- **Study Design Type**:

  Identify the specific type of study design used. Look in the methods section for explicit description of the study design.

Possible types include:

- Randomized controlled trial
- Quasi-experimental study
- Controlled before-and-after study
- Experimental study with control group
- Single-group pre-post study

If multiple design elements are present, list all that apply. If the design is not clearly stated, write "Design not clearly specified" and note where this was determined.

- **Intervention Details for Virtual Reality Training**:

  Comprehensively describe the virtual reality intervention:

- Specific technology/platform used
- Duration of VR training
- Content/skills taught through VR
- Specific features of the VR training (e.g., immersiveness, interactivity)

Extract exact details from methods section. If multiple components exist, list all. Include specific measurements like hours of training, type of VR simulation, and any unique technological characteristics.

Example format: "Immersive VR simulation using [platform], training duration: X hours, focusing on [specific skills], with [specific interactive features]"

- **Participant Characteristics**:

  Extract comprehensive participant details:

- Total number of participants
- Demographic breakdown (age, gender, professional background)
- Inclusion/exclusion criteria
- Professional domain/field of participants

Look in methods section for participant description. If ranges or means are provided for age/experience, include those. If percentages are used for demographic breakdown, include those.

Format example: "Total participants: X (Male: Y%, Female: Z%) Age range: A-B years Professional domain: [specific field]"

- **Comparative Training Method**:

  Identify and describe the comparison/control training method:

- Type of alternative training method
- Duration of comparison training
- Key characteristics of the comparison method

Extract from methods section describing how the VR training was compared. If no direct comparison was made, note ”No comparative method described”.

Ensure to capture the specific traditional training approach used (e.g., in-person lecture, standard workplace training, video-based instruction).

- **Primary Outcome Measures**:

  List all primary outcome measures used to assess VR training effectiveness:

- Specific skills measured
- Measurement tools/instruments
- Quantitative metrics used

Extract from methods and results sections. Include exact measurement scales, statistical tests used, and specific skill domains assessed.

Example format: ”Outcomes measured:

1. Skill acquisition (measured by [specific assessment])
2. Knowledge retention (measured by [specific test])
3. Performance metrics (specific quantitative indicators)”

- **Key Findings and Statistical Significance**:

  Summarize main results:

- Quantitative outcomes
- Statistical significance of findings
- Comparative effectiveness between VR and traditional training

Extract from results section. Include:

- Exact statistical values (p-values, effect sizes)
- Percentage improvements
- Comparative performance metrics

Prioritize reporting of statistically significant findings. If no significant results, clearly state ”No statistically significant differences found”.

Results

Characteristics of Included Studies

Study	Training Domain	Study Design	Sample Size	Virtual Reality Technology Type	Full text retrieved
Lohre et al., 2020a	Orthopedic surgery	Randomized controlled trial	18	Immersive virtual reality (PrecisionOS platform)	Yes
Lohre et al., 2020b	Orthopedic surgery	Multicenter, blinded randomized controlled trial	26	Immersive virtual reality (platform not specified)	No
Kim et al., 2020	Garden design (vocational education and training)	Experimental study with control group	No mention found	Immersive virtual reality application	No
Adami et al., 2021	Construction robotics	Randomized controlled trial	50	Virtual reality-based training (platform not specified)	No
Alaker et al., 2016	Laparoscopic surgery	Systematic review and meta-analysis of randomized controlled trials	31 randomized controlled trials (sample size not specified)	Proficiency-based virtual reality, haptic feedback	No
Larsen et al., 2012	Laparoscopic surgery	Systematic review of randomized controlled trials	12 randomized controlled trials (n=241)	Virtual reality simulators (proficiency-based)	No
Stone et al., 2011	Welding	Randomized controlled trial	No mention found	Virtual reality-integrated training	No
Suebnukarn et al., 2010	Dental (endodontics)	Single-group pre-post study	20	Haptic virtual reality (PHANTOM Omni haptic device)	Yes
Gallagher et al., 2013	Laparoscopic surgery	Randomized controlled trial	225	Virtual reality laparoscopic simulation	No

Study	Training Domain	Study Design	Sample Size	Virtual Reality Technology Type	Full text retrieved
Doolani et al., 2020	Manufacturing (vocational education and training)	Experimental with control, controlled before-after	30	Virtual reality storytelling (Unity3D software, HTC Vive headset)	Yes

Training domains:

- Laparoscopic surgery:3 studies
- Orthopedic surgery:2 studies
- Garden design (vocational education and training):1 study
- Construction robotics:1 study
- Welding:1 study
- Dental (endodontics):1 study
- Manufacturing (vocational education and training):1 study

Study designs:

- Randomized controlled trials (including multicenter/blinded):5 studies
- Systematic reviews or meta-analyses of randomized controlled trials:2 studies
- Experimental designs with control groups (including controlled before-after):2 studies
- Single-group pre-post design:1 study

Virtual reality technology types:

- Immersive virtual reality:3 studies
- Proficiency-based virtual reality:2 studies
- Haptic virtual reality or haptic feedback:2 studies
- Other types:virtual reality simulators (1 study) , virtual reality-based training (1) , virtual reality-integrated training (1) , virtual reality laparoscopic simulation (1) , virtual reality storytelling (1)
- Specific platforms or devices mentioned:PrecisionOS (1 study) , Unity3D (1) , HTC Vive (1) , PHANTOM Omni haptic device (1)
- No mention found of the virtual reality platform in 2 studies

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Effectiveness Analysis

Skill Acquisition Metrics

Study	Performance Metrics	Improvement Rate / Effect Size	Transfer Effectiveness Ratio (TER)	Training Duration
Lohre et al., 2020a	Objective Structured Assessment of Technical Skills (OSATS), Precision Score	OSATS: 15.9 vs 9.4 (p-value < .001); Time on Task: 59.4%	0.79	No mention found
Lohre et al., 2020b	Objective Structured Assessment of Technical Skills (OSATS), time to task, instrument handling	570% faster learning; OSATS p-value = 0.03	No mention found	11±3 min (virtual reality), 20±4 min (control)
Kim et al., 2020	Design proportion, composition, creativity	Immersive virtual reality more effective for proportion (conditional)	No mention found	No mention found
Adami et al., 2021	Knowledge, operational skills, safety behavior	Significant increase (no quantitative data)	No mention found	No mention found
Alaker et al., 2016	Objective/validated tools (varied)	Virtual reality greater than video trainers; virtual reality at least as effective as box trainers	No mention found	No mention found
Larsen et al., 2012	Operation time	17–50% reduction	No mention found	No mention found
Stone et al., 2011	Certifications, cognitive/physical parameters	41.6% more certifications (virtual reality group)	No mention found	2 weeks
Suebnukarn et al., 2010	Task time, force, bimanual coordination, outcome score	Significant improvement, p-value < 0.05 (force)	No mention found	3 days (5 sessions)
Gallagher et al., 2013	Time on Task, Transfer Effectiveness Ratio (TER), error reduction, correlation	TER: 7–42%; error reduction: 32–42%	7–42%	No mention found

Study	Performance Metrics	Improvement Rate / Effect Size	Transfer Effectiveness Ratio (TER)	Training Duration
Doolani et al., 2020	Training/recall time, accuracy, System Usability Scale (SUS)	Virtual reality faster than text (p-value < 0.05), more accurate	No mention found	2:50 min (virtual reality), 3 min (video)

Summary of outcomes and reporting across the 10 studies:

- Technical skill or performance metrics:Measured in 9 studies
- Knowledge or cognitive outcomes:Measured in 4 studies
- Certification or competency:Measured in 1 study
- Safety or behavioral outcomes:Measured in 1 study
- Quantitative effect sizes:Reported in 6 studies, including OSATS scores, percent improvement, error reduction, and time savings
- Qualitative or significant improvement only:4 studies reported only qualitative or significant improvement without quantitative effect size data
- Transfer Effectiveness Ratio (TER):Reported in 2 studies, with values ranging from 0.79 to 42%
- Training duration data:Found in 4 studies, with virtual reality training times ranging from under 3 minutes to 2 weeks; no mention found in the other 6 studies

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Retention Outcomes

Study	Follow-up Period	Retention Rate / Outcome	Comparative Performance	Skill Maintenance
Lohre et al., 2020a	No mention found	No mention found	No mention found	No mention found
Lohre et al., 2020b	No mention found	No difference in knowledge retention	Virtual reality = control (p-value = 1.0)	Maintained at post-test
Kim et al., 2020	No mention found	No mention found	No mention found	No mention found
Adami et al., 2021	No mention found	No mention found	No mention found	No mention found
Alaker et al., 2016	No mention found	No mention found	No mention found	No mention found
Larsen et al., 2012	No mention found	No mention found	No mention found	No mention found
Stone et al., 2011	No mention found	No mention found	No mention found	No mention found
Suebnukarn et al., 2010	No mention found	No mention found	No mention found	No mention found
Gallagher et al., 2013	No mention found	No mention found	No mention found	No mention found
Doolani et al., 2020	7 days	Virtual reality and 2D video greater than text manual (accuracy)	Virtual reality and 2D video equal, both greater than text	Virtual reality maintained higher accuracy

Summary of retention findings:

- Comparative data on retention or performance found in 2 studies:
  - Lohre et al., 2020b: No difference in knowledge retention between virtual reality and control (p-value = 1.0), with skills maintained at post-test (no mention found in the abstract regarding follow-up period).
  - Doolani et al., 2020: Both virtual reality and 2D video groups had higher accuracy than the text manual group, with virtual reality maintaining higher accuracy at 7-day follow-up.
- No mention found of retention, comparative performance, or skill maintenance in the other 8 studies.
- Only 1 study (Doolani et al., 2020) reported a follow-up period (7 days); no mention found for the other 9 studies.

Implementation Themes

Training Design Elements

- Most studies used immersive or interactive virtual reality environments.
- Some studies incorporated haptic feedback (Alaker et al., 2016; Suebnukarn et al., 2010) or storytelling (Doolani et al., 2020).
- Proficiency-based approaches (Alaker et al., 2016; Larsen et al., 2012) were reported as more effective than fixed-time or repetition-based training in those studies.
- The order of training modalities (such as paper sketching before immersive virtual reality) influenced outcomes in design tasks (Kim et al., 2020).

Technology Integration Factors

- Virtual reality platforms ranged from commercial surgical simulators (PrecisionOS) to custom-built applications (Unity3D software, HTC Vive headset).
- Some studies did not provide details on hardware or software, which limits reproducibility.
- Haptic and immersive features were highlighted as enhancing realism and engagement in studies that used them, though not all studies leveraged these capabilities.

Learning Environment Considerations

- Virtual reality training was generally delivered in controlled environments, often with supervision or feedback.
- Some studies allowed unlimited repetition (Lohre et al., 2020a), while others structured training by proficiency or session count.
- The degree of interactivity and immersion varied, with some systems non-interactive (Doolani et al., 2020) and others highly interactive (Suebnukarn et al., 2010).

Discussion

- Evidence base:The strongest evidence for virtual reality effectiveness in skill acquisition comes from procedural and technical domains, particularly surgical and industrial training, as supported by multiple randomized controlled trials and systematic reviews.

- Reported outcomes:These studies reported that virtual reality reduced training time and improved performance metrics compared to traditional methods.
- Retention:Evidence for long-term retention is limited, with only two studies addressing this outcome and only one reporting a follow-up period.
- Generalizability:Most studies focused on healthcare or technical trades, with fewer studies in other vocational domains, limiting generalizability.
- Variability:There was substantial variability in virtual reality technology, training design, and outcome measurement across studies, complicating synthesis.
- Sample size and reporting:Sample sizes were often small, and some studies did not provide detailed reporting of methods or outcomes, which limits the strength of inferences that can be drawn from these findings.

References

A. Gallagher, N. Seymour, Julie-Anne Jordan-Black, B. Bunting, K. McGlade, and R. Satava. "Prospective, Randomized Assessment of Transfer of Training (ToT) and Transfer Effectiveness Ratio (TER) of Virtual Reality Simulation Training for Laparoscopic Skill Acquisition." *Annals of Surgery*, 2013.

C. R. Larsen, J. Oestergaard, B. Ottesen, and J. L. Soerensen. "The Efficacy of Virtual Reality Simulation Training in Laparoscopy: A Systematic Review of Randomized Trials." *Acta Obstetricia Et Gynecologica Scandinavica*, 2012.

K. G. Kim, Catharine Oertel, M. Dobricki, Jennifer K. Olsen, A. Coppi, Alberto A. P. Cattaneo, and P. Dillenbourg. "Using Immersive Virtual Reality to Support Designing Skills in Vocational Education." *British Journal of Educational Technology*, 2020.

M. Alaker, G. Wynn, and T. Arulampalam. "Virtual Reality Training in Laparoscopic Surgery: A Systematic Review & Meta-Analysis." *International Journal of Surgery*, 2016.

Pooya Adami, Patrick B. Rodrigues, P. Woods, B. Becerik-Gerber, L. Soibelman, Yasemin Copur-Gencturk, and Gale M. Lucas. "Effectiveness of VR-Based Training on Improving Construction Workers' Knowledge, Skills, and Safety Behavior in Robotic Teleoperation." *Advanced Engineering Informatics*, 2021.

R. Lohre, Aaron J Bois, G. Athwal, and D. Goel. "Improved Complex Skill Acquisition by Immersive Virtual Reality Training: A Randomized Controlled Trial." *Journal of Bone and Joint Surgery. American Volume*, 2020.

R. Lohre, Aaron J Bois, J. Pollock, P. Lapner, Katie Mcilquham, G. Athwal, and D. Goel. "Effectiveness of Immersive Virtual Reality on Orthopedic Surgical Skills and Knowledge Acquisition Among Senior Surgical Residents." *JAMA Network Open*, 2020.

R. Stone, K. Watts, P. Zhong, and Chen-Shuang Wei. "Physical and Cognitive Effects of Virtual Reality Integrated Training." *Hum. Factors*, 2011.

S. Suebnukarn, P. Haddawy, P. Rhienmora, and Kugamoorthy Gajananan. "Haptic Virtual Reality for Skill Acquisition in Endodontics." *Journal of Endodontics*, 2010.

Sanika Doolani, Luke Owens, Callen Wessels, and F. Makedon. "vIS: An Immersive Virtual Storytelling System for Vocational Training." *Applied Sciences*, 2020.