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Blending Realities: Enhancing Vocational Welding Training Through Virtual Reality-Integrated Models

Purpose - This study examines how a hybrid approach combining virtual reality (VR) and traditional welding training can be integrated into vocational education to enhance instructional outcomes, learner engagement, and training efficiency in the United Arab Emirates.

Design/methodology/approach - A qualitative action research design was implemented across three iterative training cycles: traditional welding, VR-based instruction, and a hybrid VR–traditional model. Participants included 28 apprentices and 12 instructors at a UAE vocational training institute. Data were collected through focus groups, interviews, and participant observations, and analysed thematically.

Findings - Virtual reality was found to enhance learner motivation, reduce anxiety, and accelerate the acquisition of fundamental welding skills by providing safe, feedback-rich, and contextually relevant practice. However, VR alone could not fully replicate essential physical elements such as heat, weight, and tactile feedback. The hybrid VR–traditional model proved most effective, building confidence and procedural understanding in the VR environment before transitioning to live welding. This sequencing improved performance, reduced material waste, optimised instructor time, and increased engagement between students and instructors.

Originality/value - This study advances experiential learning theory and diffusion of innovations by demonstrating how VR can be positioned as a preparatory stage for authentic practice in vocational welding. It offers practical guidance for curriculum designers, instructors, and policymakers aiming to modernise technical training, while supporting the UAE's workforce development strategies through scalable, technology-enhanced learning models.

Keywords: Virtual Reality; Vocational Education; Welding Training; Hybrid Learning; Experiential Learning; Diffusion of Innovations.

Abbreviation	Full Term	Definition / Context in Study
XR	Extended Reality	An umbrella term for immersive technologies including Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR). Used in this study to describe digital welding simulations and other immersive learning tools.
VR	Virtual Reality	A fully immersive, computer-generated simulation that replaces the physical environment with a digital one. In this study, VR welding simulators were used for skill practice without physical risks or material waste.
AR	Augmented Reality	A technology that overlays digital information, such as graphics or instructions, onto the real-world environment. In welding training, AR can project weld paths or positioning guides directly onto workpieces.
MR	Mixed Reality	A technology blending real and virtual environments, allowing physical and digital objects to coexist and interact in real time. In welding, MR can combine real tool handling with digital guidance.
TAM	Thematic Analysis Matrix	An analytical framework informed by Saldaña (2016) used in this study to systematically compare and integrate codes from apprentices and instructors across all three action research cycles.
AWS D1.1	American Welding Society Structural Welding Code – Steel	An international industry standard for welding structural steel, referenced in the study’s practical implications for aligning XR training content with professional benchmarks.
ISO 9606	International Standard for Welder Qualification Testing	A globally recognised standard for testing and certifying welders’ competence, highlighted as a target alignment for XR-based welding modules in the UAE context.

Introduction

The global shortage of skilled trades professionals, particularly in welding, has intensified the need for innovative training models that improve both the quality and efficiency of skill development (Aichinger et al., 2025). Extended Reality (XR) is widely recognised as an umbrella term encompassing immersive technologies such as Virtual Reality (VR), Augmented Reality (AR) and Mixed Reality (MR) (Cárdenas-Robledo et al., 2022). Rauschnabel et al. (2022) argue that XR is best understood as an overarching category in which AR and VR are primary domains, with MR generally considered a subtype of AR. Although these technologies are often discussed together, they differ significantly in terms of affordances, levels of immersion and applications, making it essential to specify which technology is being examined in any given study.

In this research, while various XR modalities were considered during the design phase, the empirical focus is on Virtual Reality (VR). VR immerses users in a computer-generated environment that replaces their real-world surroundings with a simulated space where they can interact with virtual objects and scenarios. In welding training, VR allows learners to practise welding techniques such as torch positioning, travel speed and joint alignment in a highly realistic simulated workshop environment (Mohamed et al., 2025). VR welding simulators can replicate a range of welding processes and conditions, providing real-time visual, auditory and haptic feedback without the hazards or material costs of live welding. This differs from AR, which overlays digital information onto the real world, and MR, which combines real tool handling with interactive digital overlays anchored to the physical workspace.

The pedagogical affordances of VR in vocational education are considerable. VR provides an immersive and safe environment for skill practice, supports immediate and detailed feedback, enables repeated rehearsal without consuming materials and allows for the simulation of diverse welding scenarios that may be difficult or costly to reproduce in real workshops. In welding, VR can improve procedural accuracy, spatial understanding and technical confidence, particularly for beginners who may initially feel intimidated by live welding conditions. However, its effectiveness depends on thoughtful curriculum integration, instructor competence in VR facilitation and alignment with recognised industry standards.

The United Arab Emirates (UAE) has prioritised the modernisation of vocational education through initiatives such as Vision 2031 and the Emiratization agenda. Welding has been identified as a strategic skill area because of its importance to infrastructure, manufacturing and energy sectors (Yang et al., 2024). Despite increased investment in advanced training technologies, challenges remain in relation to implementation costs, variations in institutional readiness and the need for empirical evidence on how VR-based training compares with traditional, hands-on welding instruction (Arthur et al., 2025).

This study examines the integration of VR welding training systems in a UAE vocational education context using a qualitative action research approach. The research was conducted in three iterative training cycles: traditional welding as a baseline, VR-only instruction and a hybrid VR–traditional model. The investigation explores both learner and instructor perspectives and addresses the following research questions:

RQ1. What are the challenges and opportunities of implementing VR technologies in a vocational education setting in the UAE?

RQ2. How does the students' learning experience change when implementing VR technology in vocational education in the UAE?

RQ3. What is the instructors' experience of implementing VR technology in vocational education in the UAE?

Figure 1 illustrates the research framework.

Figure 1. The Research Framework

Literature Review

Virtual Reality: Concepts, Affordances, and Adoption

Virtual Reality (VR) is a core technology within the broader family of extended reality (XR) that fully immerses the user in a computer-generated environment, replacing real-world surroundings with a simulated setting (Cárdenas-Robledo et al., 2022; Çöltekin et al., 2020). This immersive environment can recreate complex scenarios, allowing users to interact with virtual objects and receive real-time feedback (Khassawneh et al., 2025). In welding training, VR systems replicate authentic workshop conditions, enabling learners to practise tasks such as torch positioning, travel speed, and joint alignment without the hazards or material costs associated with live welding.

Key affordances relevant to technical education include the ability to simulate diverse scenarios, provide immediate performance feedback, visualise otherwise hidden parameters, and track progress through integrated analytics. These features can reduce early error rates, conserve consumables, and provide a safe space for repeated practice (Radianti et al., 2020; Xi et al., 2023). From the perspective of experiential learning theory (Kolb, 1984), VR supports all stages of the learning cycle by allowing learners to gain concrete experience in a simulated environment, reflect on performance, conceptualise improvements, and actively experiment with new approaches.

The adoption of VR in vocational contexts aligns with Rogers' (2003) Diffusion of Innovations model. Relative advantage is evident in enhanced safety, increased efficiency, and richer feedback compared to traditional training alone. Compatibility is strengthened when VR content maps directly to curriculum standards and industry requirements (Bourini et al., 2025). Perceived complexity can be reduced by providing turnkey solutions, simple calibration processes, and targeted professional development. Trialability is supported through small-scale pilots in selected modules, while observability increases when progress dashboards, recorded performance data, and instructor testimonials clearly show the benefits of VR training (Davis, 1989; Škola et al., 2023; Wu et al., 2025).

Virtual Reality in Vocational Education

Across vocational fields, VR is being used to standardise training, expand safe practice opportunities, and offer detailed performance tracking where instructor time or equipment availability may be limited (Radianti et al., 2020; Khlaif et al., 2024). By simulating realistic work environments, VR enables learners to follow correct sequences, avoid typical novice errors, and receive feedback that is both immediate and context-specific.

A practical delivery model is emerging in which learners alternate between VR training stations and physical workshops, allowing them to acquire basic competencies in the simulator before applying them to live equipment (Khassawneh et al., 2024). This sequencing can increase throughput, preserve equipment for advanced practice, and ensure that instructor attention is focused on high-value, hands-on tasks. VR also supports blended and remote learning models by enabling learners to access training modules outside of the physical workshop, maintaining progress even when access to live equipment is restricted (Al-Obeidi et al., 2024).

However, barriers to adoption remain. These include initial investment and maintenance costs, variability in institutional infrastructure, and challenges in aligning VR scenarios with qualification frameworks (Owais et al., 2020; Mohamed & Sicklinger, 2022). Instructor readiness is another concern, as educators may need additional training to effectively integrate VR into teaching practice (Škola et al., 2023; Wu et al., 2025). In the United Arab Emirates, policy initiatives such as Vision 2031 and Emiratization create favourable conditions for adoption, but equitable access, culturally relevant content, and consistent technical support remain important considerations (Jarrah & Alkhasawneh, 2023; Mustafa et al., 2025).

According to diffusion principles, successful adoption is most likely when institutions clearly demonstrate the relative advantage of VR (e.g., reduced rework, faster attainment of skills), ensure compatibility with current curricula, reduce complexity through user-friendly systems, increase trialability via pilot implementations, and improve observability through measurable performance gains and case examples.

Virtual Reality in Welding Training

Welding demands precise spatial awareness, steady motor control, and strong safety practices. VR welding simulators recreate a range of welding processes and conditions, allowing trainees to practise without physical hazards (Khassawneh & Mohammad, 2025). Learners can develop essential skills such as maintaining correct torch angle, controlling travel speed, and achieving proper bead placement while receiving immediate visual, auditory, and haptic feedback (Veningston & Rajendran, 2024; Alfaro-Viquez et al., 2025). Studies have shown that synchronised feedback—where corrective prompts are timed to the learner's actions—improves technique and reduces errors during skill acquisition (Ceyssens et al., 2024).

Within a welding curriculum, VR training modules should reflect the specific joints, positions, and procedures required for assessment, such as those defined by AWS D1.1 or ISO 9606. Built-in analytics can track parameters like torch angle variance, speed stability, and arc time, enabling instructors to target feedback and learners to self-assess (Al Sulaity et al., 2025). As competence develops, feedback can be gradually reduced to promote independent performance in live welding contexts.

From an adoption perspective, the relative advantage of VR welding is most apparent when institutions can demonstrate reductions in consumable use, shorter times to achieve acceptable weld quality, and improved safety during initial training phases (Al-Ali et al., 2025). Compatibility is enhanced when VR simulations replicate local equipment and welding processes. Complexity can be reduced with straightforward calibration routines and intuitive instructor dashboards. Trialability can start with a limited set of welds, for example a fillet weld in the 2F position, before expanding to more advanced scenarios. Observability improves when comparative results (before and after VR training) and cohort-level performance metrics are shared with stakeholders (Rogers, 2003; Davis, 1989; Gerhard, 2024; Shankhwar & Smith, 2022; Shankhwar et al., 2022).

Prior VR welding research frequently reports objective skill outcomes such as weld quality, certification readiness, or time-to-criterion using simulator or exam metrics (for example Shankhwar & Smith, 2022; Shankhwar et al., 2022). A complementary stream examines XR adoption qualitatively, focusing on educator preparedness, institutional enablers, and perceived usefulness in context (for example Škola et al., 2023; Khlaif et al., 2024). This study adds value at the intersection of these strands by offering an in-depth qualitative action research account of a hybrid VR to live sequence in a UAE vocational setting, triangulating apprentices' and instructors' perspectives with observation, and making the implementation chain transparent through documented workflows and analytics. Methodologically, it is anchored in established qualitative procedures used in technical education research, including structured focus groups (Krueger & Casey, 2014), code-based thematic analysis and matrix comparison (Saldaña, 2016; Zairul, 2025), and saturation as a completeness criterion (Guest et al., 2006). In doing so, the study complements outcome-oriented VR evaluations with contextualised evidence about how and why hybrid models work in practice, and it complements adoption studies by linking perceptions to concrete pedagogical sequencing and transfer.

Method

Research Design and Approach

This study employed a qualitative action research methodology within a technical education setting. Action research was selected because it enables the implementation of an intervention—in this case, VR-based welding training—and the iterative refinement of practices while closely involving participants in the evaluation of changes. This approach is well suited to educational innovation, as it focuses on solving practical problems and generating actionable insights through repeated cycles of planning, action, observation, and reflection.

In this study, the action research was structured into three cyclical phases, each corresponding to a different training mode:

- **Cycle 1 – Traditional Welding Training (baseline):** apprentices learned welding using conventional tools, materials, and equipment in a live workshop environment.
- **Cycle 2 – Virtual Reality Welding Training:** the same apprentices learned and practised welding techniques using a VR welding simulator that replicates workshop conditions, provides real-time visual and auditory feedback, and allows repeated practice without material waste or safety risks.
- **Cycle 3 – Hybrid Training:** a blended approach in which apprentices first developed skills on the VR simulator before transitioning to live welding tasks within the same cycle.

Each cycle represented an intervention phase, after which qualitative data were collected to capture both apprentice and instructor experiences and perceptions of outcomes. Comparing results across cycles made it possible to identify how learning and teaching experiences differed between traditional, VR-only, and hybrid approaches, and to use these insights to inform the design of the subsequent cycle. This iterative refinement ensured that the final hybrid model built on the strengths and addressed the limitations identified in earlier phases.

Participants and Setting

The research was conducted at a vocational training institute in the United Arab Emirates within a welding training program. A total of 40 individuals participated, including 28 apprentice students and 12 welding instructors. The apprentice group comprised both first-year and second-year students enrolled in a welding certification track, with ages ranging from the late teens to the mid-twenties. Skill levels varied; some apprentices had no prior welding experience while others had up to two years of training experience.

The instructor participants were experienced welding trainers with professional welding backgrounds ranging from five to twenty years. All instructors were male, reflecting the current gender composition in this trade program. While most were experienced in traditional welding pedagogy, they were new to using VR technology for teaching. Prior to Cycle 2, instructors received an orientation on the VR welding simulator's operation and features to ensure they could assist students effectively and interpret simulator-generated feedback reports. Table 1 provides information about the demographics of the participants.

Table 1. Participant Demographics

Apprentices (n = 28)

Characteristic	Category	n	%
Age band	18–20	10	35.7%
	21–23	12	42.9%
	24–26	6	21.4%
Course year	Year 1	15	53.6%
	Year 2	13	46.4%
Prior welding experience	None (0 months)	12	42.9%
	≤ 6 months	7	25.0%
	7–12 months	5	17.9%
	13–24 months	4	14.3%
Gender	Male	26	92.9%
	Female	2	7.1%
	Other / prefer not to say	0	0.0%

Instructors (n = 12)

Characteristic	Category	n	%
Age band	25–34	3	25.0%
	35–44	6	50.0%
	45–54	3	25.0%
Prior welding experience	5–9 years	4	33.3%
	10–14 years	5	41.7%
	15–20 years	3	25.0%
Gender	Male	12	100.0%
	Female	0	0.0%
	Other / prefer not to say	0	0.0%

Reflexivity and Bias Mitigation

Qualitative materials were coded by the first author (participant-observer and facilitator of focus groups/interviews) and the third author (not involved in delivering instruction). A shared codebook was developed after Cycle 1 and refined across Cycles 2–3; 33% of transcripts, balanced by cycle and role (apprentice/instructor), were independently double-coded to assess reliability. Discrepancies were resolved through line-by-line discussion to consensus, with decisions, rationales, and any codebook edits documented in an audit trail; when interpretations diverged (e.g., “engagement” vs “competition”), earlier transcripts were spot-checked to prevent drift. To mitigate bias from the first author’s dual role, both coders maintained reflexive memos (including explicit bracketing of assumptions about VR efficiency and safety) and held periodic peer debriefs with the wider team to probe negative cases and rival explanations. Member-checking involved returning de-identified thematic summaries (with exemplar quotes) to all instructors and to apprentices during scheduled debrief sessions; response rates were 100% of instructors (12/12) and 100% of apprentices (28/28), with comments focused on wording clarity and examples rather than disputing themes. Triangulation across apprentice perspectives, instructor interviews, and observation notes further strengthened credibility.

Data Collection Procedure

A combination of focus groups, one-on-one interviews, and participant observations was used to gather qualitative data during each cycle. After the training sessions in Cycle 1 and Cycle 2, apprentice participants took part in semi-structured focus group discussions with four to six participants, facilitated by the researcher. These discussions encouraged apprentices to reflect on their learning experience, the challenges they encountered, and their emotional and cognitive responses to the training environment. The group setting promoted open dialogue and allowed participants to build on each other’s observations, generating richer insights into group dynamics and shared experiences.

Following the guidance of Krueger and Casey (2014), open-ended questions were used to explore perceptions of engagement, safety, skill development, and overall satisfaction. For example, after Cycle 1 (traditional training), apprentices were asked to describe what they found most difficult or intimidating about welding for the first time. After Cycle 2 (VR training), they discussed differences they noticed compared to working in a live welding bay.

Instructors were interviewed individually using semi-structured protocols after each cycle. These interviews examined their observations of student performance, perceived teaching challenges or advantages of each training method, and professional views on training effectiveness. This individual format allowed instructors to speak freely about issues such as technical limitations, curriculum alignment, or pedagogical considerations they might not have shared in a group setting.

The researcher also acted as a participant-observer during all training sessions, recording non-intrusive field notes on student attentiveness, frequency of errors, need for instructor intervention, and any notable incidents such as a student startled by a welding spark in Cycle 1 or a student celebrating a high score on the VR simulator in Cycle 2. These observations helped contextualise and triangulate the self-reported data from interviews and focus groups.

Data collection continued until thematic saturation was reached, defined as the point at which no new codes or insights emerged from additional discussions or interviews. Following the approach outlined by Guest, Bunce, and Johnson (2006), saturation was used to determine both sample adequacy and completeness of thematic coverage. By the end of Cycle 3, the repeated emergence of dominant themes such as perceived realism, engagement, skill acquisition, and instructional effectiveness across participant groups indicated that the dataset was comprehensive, strengthening the credibility and trustworthiness of the findings.

VR learning environment comprised dedicated welding stations (head-mounted display, haptic torch controller, inside-out tracking, VR-ready workstation) that delivered curriculum-aligned fillet and groove scenarios with real-time guidance overlays and post-attempt analytics such as torch-angle variance, speed stability, and arc-on time. Sessions followed a standard workflow: orientation to calibration to guided drills to unguided attempts to instructor debrief. Learners then transitioned to equivalent live tasks once mastery thresholds were met. Photograph is provided in Figure 2.

Figure 2. VR Learning Environment

Data Analysis

The analysis followed a thematic analysis using a matrix approach (TAM), drawing on the coding guidelines outlined by Saldaña (2016) for identifying patterns in qualitative data. Initially, transcripts were open-coded to label discrete ideas or observations (e.g., “fear of injury”, “waiting time frustration” in Cycle 1; “enjoyed virtual practice”, “missed real spark/heat” in Cycle 2; “felt more confident entering real weld after VR practice” in Cycle 3). Codes were first generated separately for apprentice data and instructor data in each cycle, then consolidated into a matrix to facilitate comparison and integration, leading to the formation of broader themes per cycle.

For example, in Cycle 1 the codes grouped into themes such as Benefits of Traditional Training (authentic environment, hands-on practice) and Challenges of Traditional Training (safety hazards, inefficiency). In Cycle 2, a prominent theme was XR as an Effective Intermediate Tool, capturing how virtual training helped build basic skills and confidence. Cycle 3 yielded themes like

Preference for Hybrid Training and Improved Skill Development in Hybrid Approach, reflecting participants' overall favoring of the blended method.

The iterative nature of action research meant that analysis was ongoing. After Cycles 1 and 2, preliminary findings were reviewed and fed into planning Cycle 3. The final analysis compared themes across all three cycles using the TAM framework to draw conclusions about how learning experiences evolved (Zairul, 2025).

To enhance the robustness of findings, data triangulation was employed: the study compared apprentice perspectives with instructor perspectives, and also integrated observational evidence. For instance, if apprentices claimed that VR training saved time, the researcher's observations of session lengths and idle times were checked to substantiate that claim. The interpretive framework was informed by a constructivist paradigm, recognizing that each participant's experience was subjective yet socially constructed through group interactions. To maintain credibility, member checking was conducted in a modest but targeted form. After the preliminary analysis for each cycle, emergent findings and draft thematic representations were summarized and presented to participants, with a particular focus on instructors, to confirm whether the themes accurately captured their perspectives and experiences. Participants were invited to comment on the accuracy, completeness, and relevance of the thematic summaries, and their feedback was considered in refining theme labels and definitions.

The relatively small, focused sample and in-depth engagement with participants lend confidence that the themes identified accurately reflect the group's shared and individual experiences in this setting. While the findings are context-specific to one institution and not intended for broad statistical generalizability, they aim to provide context-rich insights and to inform future research and practice in similar training environments.

Results

After implementing the three action research cycles, the study uncovered several key themes regarding the use of XR in welding training. The findings, analyzed using a thematic analysis with a matrix approach (TAM) informed by Saldaña's (2016) coding framework, are organized by cycle to illustrate how each phase contributed new insights. Figure 3 presents the process and findings.

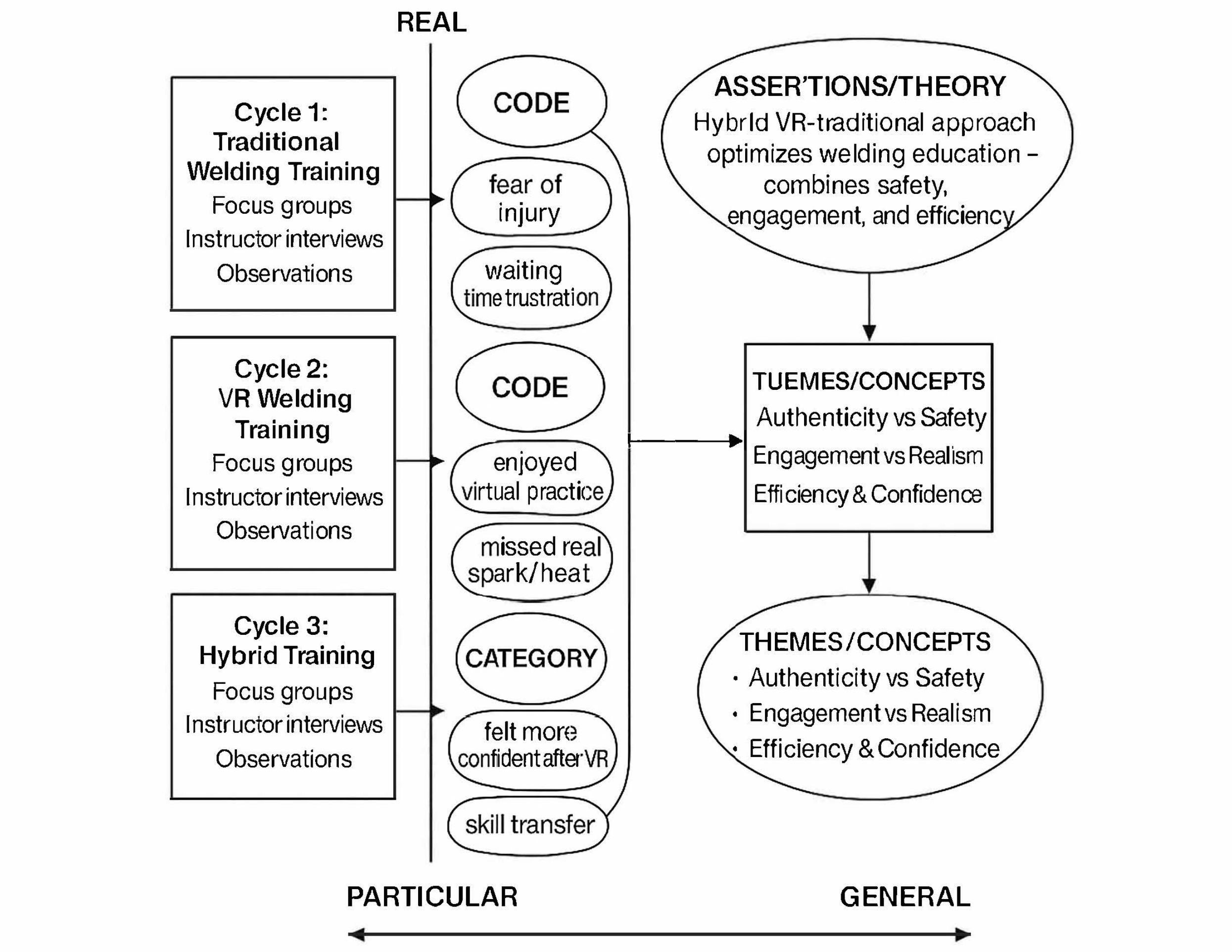

Figure 3. Summary findings using thematic analysis with a matrix approach (TAM).

We did not collect institution-specific cost data; however, implementation typically involves (i) capital outlay for VR welding stations (headset, haptic torch, tracking sensors, PC), (ii) recurring software licensing and hardware maintenance, and (iii) instructor time for onboarding and curriculum alignment. A pragmatic rollout is a staged pilot (1–2 stations) with brief instructor PD (≈8–12 hours initially; ≈2–4 hours/term thereafter), followed by a hybrid rotation that leverages VR for early practice to reduce consumables and booth bottlenecks. Feasibility should be judged via a simple payback model that tracks: time-to-acceptable weld, consumables per student, instructor contact minutes, and incident reports; payback = [(baseline − hybrid) consumables + saved instructor hours × loaded rate] ÷ (capital + annual license + maintenance), with a 10–15% contingency and a 3–5-year refresh cycle. Institutions should obtain total-cost-of-ownership quotes from multiple vendors, plan for IT support and headset sanitization/replacement, and use pilot metrics to inform scale-up.

Cycle 1: Traditional Welding Training (Baseline)

In the first cycle, apprentices participated in standard welding training using live welding machines, metal workpieces, and classroom-based instruction on safety and technique. This stage established a reference point for how skills are traditionally developed, which is central to understanding the challenges and opportunities of implementing VR in the UAE vocational context (RQ1). It also provided a baseline for examining changes in student learning experiences (RQ2) and instructor experiences (RQ3) once VR was introduced.

Challenges in the live training environment

For apprentices, the sensory and physical intensity of the welding environment was a significant challenge. Many reported feelings of fear and hesitation during their first attempts. The combination of bright flashes, flying sparks, loud crackling, and intense heat often caused physical withdrawal from the task. One novice apprentice stated, *"I was afraid I will get burned… the electricity and sparks were very scary"*. This reaction illustrates how the embodied dimension of welding, where the body's sensory input is deeply intertwined with the learning process, can initially act as a barrier to engagement.

Instructor observations supported these accounts. Some students visibly flinched or stepped back when sparks appeared, and others were reluctant to weld for more than a few seconds at a time due to heat discomfort. Instructors acknowledged that overcoming such sensory overwhelm often requires repeated exposure, which lengthens the early learning phase.

The second major challenge was logistical. Limited welding booths and machines meant that apprentices had to take turns, often spending long periods watching others rather than practising themselves. A student with no prior experience described *"long waiting periods during training with conventional machines"*, adding that only one or two students could weld at a time. Instructors confirmed that these delays reduced opportunities for repetition, which is critical in experiential learning for consolidating procedural memory.

Opportunities in authentic practice

Despite the difficulties, apprentices and instructors highlighted the authenticity of live welding as a powerful learning advantage. Apprentices developed tactile familiarity with the torch, adapted to the weight of protective equipment, and experienced the physical consequences of mistakes. For example, welding too slowly could burn through the metal, while incorrect angles resulted in visible bead defects. Instructors argued that these tangible outcomes deepen understanding in ways that simulators cannot. One commented that *"a welder must respect the hazards"*, and that supervised exposure to real heat and sparks fosters both technical skill and safety discipline.

Interpretive insights in relation to RQs

Cycle 1 findings highlight that, in response to RQ1, traditional welding offers rich opportunities for embodied skill development and safety training but also presents challenges of fear, inefficiency, and resource constraints. Regarding RQ2, the apprentices' learning experience in this cycle was characterised by high realism but also high stress and limited practice time. For RQ3, instructors valued authenticity but recognised the constraints on skill repetition and teaching efficiency. These insights suggested that VR could address some of these barriers while preserving the benefits of authentic practice.

Cycle 2: VR-Based Welding Training

In the second cycle, apprentices trained exclusively with a VR welding simulator. The system featured a realistic torch and helmet interface connected to software that projected a fully immersive virtual welding environment, complete with a workpiece and weld pool display. This design allowed apprentices to rehearse core skills such as bead placement and arc length without engaging in live welding. This cycle addressed RQ1 by testing whether VR could mitigate the challenges observed in Cycle 1, RQ2 by examining how the absence of real-world risk influenced the student learning experience, and RQ3 by capturing instructors' perspectives on VR as a teaching tool.

Opportunities for engagement and skill-building

Apprentices consistently described the VR training as engaging, interactive, and enjoyable. Game-like scoring features encouraged friendly competition and repeated attempts. One apprentice noted, *"It felt like a challenge to get all parameters right – I wanted to do it again and again until I got a perfect score"*. This environment encouraged high-frequency repetition without the delays or material costs inherent in live welding.

From an experiential learning perspective, VR removed the anxiety linked to heat, sparks, and burns, allowing learners to concentrate on refining motor skills. Instructors observed that students who had struggled to strike an arc in Cycle 1 were able to do so quickly in VR, suggesting that the removal of high-stress sensory input accelerated early skill acquisition.

Limitations in embodied realism

While VR offered safety and efficiency, it lacked the sensory authenticity of live welding. Apprentices recognised that the virtual environment was *"too comfortable"*, noting the absence of heat, weight, and noise. This absence reduced the embodied learning experience, as sensory cues play a central role in physical skill acquisition. Instructors voiced concern that students might become overconfident in a risk-free setting, potentially underestimating the hazards of real welding.

The VR environment also omitted certain essential tasks such as clamping workpieces, cleaning welds, or adjusting physical machine settings. One instructor pointed out that *"in VR, the workspace is fixed, and students do not have to move or manage cables like in a real booth"*, indicating a gap in training authenticity.

Interpretive insights in relation to RQs

For RQ1, VR effectively addressed logistical inefficiencies and reduced safety risks, but it introduced new limitations around skill transfer to real-world contexts. Regarding RQ2, the student experience shifted from high-stress, limited repetition to low-stress, high repetition, but at the expense of authentic embodied engagement. For RQ3, instructors valued VR's capacity to provide constant, personalised feedback but stressed that it should not replace live training for developing hazard awareness and physical adaptability.

Cycle 3: Hybrid VR–Traditional Training

In the third cycle, apprentices followed a hybrid sequence: first practising a welding skill in VR until demonstrating proficiency, then performing the same skill on live equipment. This structure was intended to combine VR's advantages in engagement, repetition, and safety with the authentic sensory and contextual learning of traditional welding. The design directly addressed RQ1 by testing an integrated implementation model, RQ2 by evaluating how learning experiences changed when transitioning between modalities, and RQ3 by examining instructor experiences in this blended approach.

Enhanced performance and efficiency

The hybrid model yielded the strongest outcomes of the three cycles. Apprentices described smoother transitions to live welding, greater confidence, and faster mastery of techniques. One novice commented, *"The hybrid method gave me confidence. I knew what to expect when I struck the arc for real because I had sort of done it before in VR"*. Instructors observed that students achieved acceptable weld quality in fewer attempts, conserving materials and freeing up time for advanced instruction.

From an experiential learning perspective, VR appeared to reduce the cognitive and emotional load of the first encounter with live welding, enabling students to progress more rapidly into meaningful practice. This efficiency addressed RQ1's concern with implementation benefits and demonstrated how sequencing modalities can shorten the learning curve without sacrificing skill quality.

Layered embodiment and confidence-building

The hybrid approach demonstrated a progressive embodiment effect. In VR, students rehearsed the mechanics of torch handling and bead placement in a controlled, low-risk environment. Live welding then reintroduced the full sensory demands of heat, noise, weight, and tactile feedback, allowing learners to integrate motor skills with authentic environmental engagement. For RQ2, this layered approach balanced confidence-building with realistic skill application, while for RQ3, instructors found that students arrived better prepared, enabling more targeted coaching and less repetitive safety instruction.

Integration considerations

Participants stressed that VR practice must closely mirror the live tasks for maximum benefit. Apprentices who moved directly from a VR scenario to its real-world equivalent reported strong skill transfer, while those who trained on unrelated virtual tasks found the VR practice less relevant. Instructors also highlighted the need to develop students' independent judgment once VR feedback is removed. Some incorporated self-assessment exercises into the live component to ensure that learners could evaluate weld quality without relying on the simulator's scoring.

Interpretive insights in relation to RQs

Cycle 3 findings strongly support RQ1 by showing that a well-integrated hybrid model can harness VR's benefits while mitigating its limitations. For RQ2, the data suggest that alternating between partial and full embodiment can enhance learning by reducing initial stress while maintaining authentic skill development. For RQ3, instructors experienced a shift toward more efficient, higher-quality teaching, with the hybrid approach reducing fatigue and increasing satisfaction. A cross-cycle synthesis linking themes to evidence and implications is provided in Table 2.

Table 2. Themes, Evidence, RQ Coverage, and Practical Implications

Final theme	Representative quote (de-identified)	RQ(s)	Immediate practical implication
Authenticity & embodied learning (live)	"The heat and sparks made me hold the torch differently—VR didn't make me feel that." (Apprentice, C1)	RQ2	Retain live booths for sensory calibration and hazard discipline; don't replace with VR.
Safety & anxiety reduction (VR)	"In VR I wasn't scared of getting burned, so I finally focused on	RQ1, RQ2	Use VR to stage the first encounters and reduce affective load before live welding.

Final theme	Representative quote (de-identified)	RQ(s)	Immediate practical implication
	angle and speed.” (Apprentice, C2)		
Repetition & feedback efficiency (VR)	“They got instant scores and tried again right away—no waiting for a booth.” (Instructor, C2)	RQ1, RQ3	Schedule high-frequency VR drills to build fundamentals while conserving consumables.
Engagement & motivation (VR gamification)	“I kept going until I hit a perfect score.” (Apprentice, C2)	RQ2	Leverage scoring/targets to set mastery thresholds before progressing to live tasks.
Transfer gaps from VR-only	“In VR the workspace is fixed; in the booth you have to manage clamps and cables.” (Instructor, C2)	RQ1, RQ3	Pair VR tasks with equivalent live set-ups (clamping, cleanup) to close authenticity gaps.
Progressive embodiment via hybrid sequence	“VR gave me confidence; when I struck the arc for real, I knew what to expect.” (Apprentice, C3)	RQ2	Adopt VR→live sequencing as default for novice units to smooth the transition.
Improved throughput & instructor time (hybrid)	“Students reached acceptable welds in fewer attempts—more time for coaching.” (Instructor, C3)	RQ1, RQ3	Rotate cohorts between VR and live bays to optimize utilization and enable targeted feedback.
Feedback dependency (risk)	“Without the VR score, some students struggled to judge bead quality.” (Instructor, C3)	RQ2, RQ3	Fade VR feedback over time; add self-assessment rubrics before live checks.
Task congruence matters	“When the VR task matched the real joint, transfer was much easier.” (Apprentice, C3)	RQ1, RQ2	Align VR modules one-to-one with assessed live joints/positions (e.g., 2F, 3G).
Instructor adoption shift	“I was skeptical, but the hybrid saved time on basics and improved readiness.” (Instructor, C3)	RQ3	Provide brief, hands-on PD and early pilot wins to build instructor buy-in.

Notes: C1 = Cycle 1 (traditional), C2 = Cycle 2 (VR), C3 = Cycle 3 (hybrid). Quotes are de-identified exemplars; adjust phrasing to match your transcripts verbatim if needed.

Discussion

This study reinforces and extends prior findings in the VR and vocational training literature, with the thematic analysis demonstrating that a hybrid VR–traditional approach offers the most balanced and effective training model in the UAE vocational context. The results clearly address

RQ1 by showing that VR implementation presents significant opportunities in engagement, efficiency, and skill acquisition, while also posing challenges in realism, safety discipline, and embodied learning. These insights support Cárdenas-Robledo et al. (2022), who emphasised the pedagogical benefits of embedding immersive technologies within blended learning environments. Empirical evidence from all three cycles confirms that VR produces the strongest outcomes when sequenced with real-world practice, where foundational skills developed in the virtual environment are reinforced through live, sensory-rich experience. This finding aligns with experiential learning theory (Kolb, 1984), which posits that learning is most effective when it integrates conceptual understanding, practical application, and reflective refinement in diverse contexts.

With respect to RQ2, the data show that VR significantly changes the student learning experience by reducing anxiety, increasing practice repetitions, and accelerating early-stage skill acquisition. However, the transition from high-stress realism in Cycle 1 to low-stress virtual practice in Cycle 2 also revealed a trade-off in embodied engagement. Apprentices reported that VR lacked the tactile feedback, physical discomfort, and hazard awareness that are integral to mastering welding in authentic contexts. This is consistent with Mystakidis et al. (2022) and Morimoto et al. (2022), who note that psychomotor skills require full sensory immersion and direct interaction with equipment. Thematic mapping in this study confirmed that full embodiment is best achieved progressively, as demonstrated in the hybrid model (Cycle 3), where VR acted as a scaffold to build confidence before moving into high-stakes, fully embodied live welding.

For RQ3, the iterative, participatory nature of the action research cycles contributed to a significant shift in instructors' perceptions, from initial scepticism about VR's value to strong advocacy for its integration in a hybrid format. This transformation was closely linked to their direct observations of improved student readiness, reduced time spent on introductory safety drills, and more opportunities for targeted skill coaching. Viewed through Rogers' Diffusion of Innovations theory, these findings suggest that experiential proof of VR's benefits in an instructor's own teaching context can be critical for overcoming adoption barriers and fostering sustained buy-in.

Collectively, these findings affirm the practical benefits of hybrid VR–traditional training and contribute to theoretical discussions on technology integration in vocational education. The study supports the view that VR cannot fully replace traditional methods due to the irreplaceable role of physicality in skill mastery. At the same time, it advances the concept of progressive embodiment, in which VR and live practice are deliberately sequenced to optimise both cognitive preparation and sensory–motor skill development. This integrated approach provides a pedagogical model for vocational education that addresses the challenges and opportunities identified in RQ1–RQ3, while also contributing to the wider discourse on VR's role in transforming skill-based learning.

Theoretical Implications

This study advances theoretical understanding in vocational education by showing how Virtual Reality (VR) can be effectively integrated within the frameworks of experiential learning theory (Kolb, 1984) and the diffusion of innovations (Rogers, 2003). From an experiential learning perspective, the findings indicate that VR is most effective when used as a preparatory stage before authentic, hands-on welding. This sequencing allows learners to engage in concrete experiences within an immersive simulated environment, reflect on their performance through immediate feedback, conceptualise corrective strategies, and then reapply them in live welding tasks. This mirrors the experiential learning cycle and supports earlier research that emphasises immersive, situated learning for skill development (Alfaro-Viquez et al., 2025; AlGerafi et al., 2023; Okimoto et al., 2015). By combining VR training with live practice, the approach also addresses concerns raised by Aichinger et al. (2025) and McGrath and Yamada (2023) about the need for vocational training models that modernise delivery while preserving authenticity and tacit trade knowledge.

The study also contributes to Diffusion of Innovations theory by identifying the factors that facilitated adoption among instructors. As in Akour and Alenezi (2022) and Al-Obeidi and Mohamad Ali (2024), perceived usefulness—particularly improvements in learner readiness, efficiency, and safety—was a decisive factor in building acceptance. Compatibility was strengthened when VR scenarios aligned with existing welding curricula, industry standards, and assessment protocols, echoing the importance of contextual fit highlighted by Owais et al. (2020) and Mohamed and Sicklinger (2022). Perceived complexity was reduced through targeted instructor training and intuitive simulator design, supporting Rogers' proposition that lowering barriers to entry increases uptake. Trialability was achieved through phased implementation in selected modules, and observability improved as instructors and decision-makers saw measurable performance gains, reflecting patterns seen in other immersive education adoption studies (Khlaif et al., 2024; Wu et al., 2025).

By integrating experiential learning theory and Diffusion of Innovations theory, the research provides a coherent framework for both the design and adoption of immersive training in vocational contexts. Experiential learning theory explains how VR accelerates procedural fluency and prepares learners for live application. Diffusion of Innovations theory identifies the adoption levers—relative advantage, compatibility, reduced complexity, trialability, and observability—that support sustainable integration. These findings contribute to the growing body of evidence (Bailey & Won, 2024; Fernández-Cerero et al., 2025) showing that when implemented strategically, VR can modernise vocational training while maintaining the core experiential elements essential to skill mastery.

Practical implications

Institutions should adopt Virtual Reality as part of a hybrid strategy that sequences virtual practice with live welding to optimise skill development. Findings tied to the TAM themes of confidence progression and safety acclimatisation indicate that VR is most effective for early familiarisation, followed by immediate live application to consolidate correct technique under authentic conditions. In welding, this means first using VR to stabilise torch angle, travel speed, and stand off, then assigning the equivalent live joint and position to integrate physicality, tactile feedback, and hazard awareness.

The recommendation to make hybrid sequencing the default is supported by the progressive embodiment and authenticity and embodied learning themes. Setting clear mastery thresholds in VR and then requiring an equivalent live attempt in the same joint and position within the same session strengthens transfer. Task mapping is reinforced by the task congruence matters and transfer gaps from VR only themes, which show that alignment between simulator scenarios and assessed live work improves skill carryover.

Instructor professional development is warranted by the feedback dependency and instructional adaptability themes. Training should cover interpretation of simulator analytics such as angle variance, speed stability, and arc on time, and how to translate those data into concise live coaching cues. The fading of digital prompts is also indicated by the feedback dependency theme, suggesting a gradual reduction of on-screen guidance and the use of self-assessment rubrics so students can judge bead quality without scores before moving to live work.

Operationally, throughput gains and station rotation are supported by the instructional efficiency and engagement and motivation themes. Rotating cohorts between VR stations and live bays reduces waiting time, conserves consumables, and frees instructor attention for targeted feedback. Curriculum and standards alignment follow from the industry relevance and compatibility themes and points to mapping VR scenarios and analytics to AWS D1.1 and ISO 9606, with multilingual support including Arabic for accessibility in the UAE context. Instructor adoption and change management are aided by evidence from the instructor adoption shift theme, suggesting short hands on pilots that demonstrate quick wins and peer mentoring to build confidence.

A brief cost and feasibility note support transferability. While institution specific cost data were not collected in this study, a staged pilot with one to two VR stations, an initial instructor training block of roughly 8 to 12 hours, and ongoing refresh of about 2 to 4 hours per term is advisable. Programs should track consumables per student, time to acceptable weld, instructor contact minutes, and incident reports to estimate simple payback and inform scale up. These metrics can also support a future cost benefit analysis comparing traditional, VR only, and hybrid models.

Limitations and Future Research Directions

This study has several limitations that should be considered when interpreting the findings. First, the sample size was relatively small and drawn from a single vocational training institution in the UAE. This limits the generalisability of the results to other settings, cultures, and vocational disciplines. Future research should seek to replicate this study across multiple institutions and with a broader demographic profile, including female trainees and participants from a range of technical trades.

Second, the assessment of student learning was primarily qualitative, relying on instructor observations, student feedback, and thematic analysis. Objective measures such as standardised welding certification tests or independent third-party evaluations were not used, which may affect the precision of the learning outcome data. A mixed-methods approach that incorporates quantitative skill assessments alongside qualitative insights would strengthen the robustness of future studies.

Third, the researcher's involvement in the implementation process introduces the potential for bias, despite efforts to triangulate data sources and validate themes through participant feedback. While the action research design was valuable for iterative improvement, it may have influenced neutrality.

Fourth, the VR technology used in this study represents only one type of available system, and the results may vary with different software, hardware, or content designs. No direct comparisons between different VR platforms were made, which limits insights into best-in-class tools or feature sets.

Our instructor cohort was all male (12/12), reflecting the program and trade context; this homogeneity may limit transferability to settings with more gender-diverse instructional teams. Instructor gender can influence classroom climate, feedback, and role-modeling, so effects of VR/hybrid training observed here may differ elsewhere. Future work should purposefully include gender-diverse instructor samples to test generalizability.

In addition, future research should explore larger-scale, controlled studies comparing traditional, VR-only, and hybrid VR–traditional training models using standardised assessments of psychomotor skill acquisition, retention, and transfer to workplace performance. Longitudinal studies are particularly needed to assess the lasting impact of VR training on job readiness and long-term skill retention.

Further investigations into the optimal sequencing and duration of VR versus live practice could yield evidence-based guidelines for curriculum design. Researchers could also examine whether certain welding skills are better suited to VR-based instruction and whether VR can be adapted to individual learning styles through adaptive learning technologies.

Cost–benefit analyses tailored to institutional contexts in the UAE and other regions would help guide policy and investment decisions. Cross-cultural studies could also explore how local educational cultures, language support, and industry expectations influence VR adoption, effectiveness, and learner engagement.

Finally, Future work should conduct a formal cost-effectiveness analysis comparing traditional, VR-only, and hybrid models using standardized performance outcomes and full economic accounting.

Conclusion

This study examined the integration of virtual reality (VR) into vocational welding training in the United Arab Emirates through three action research cycles: traditional training, VR-based training, and a hybrid model. Results show that VR enhances learner engagement, confidence, and early skill calibration by providing safe, feedback-rich, and contextually relevant practice. However, VR cannot fully replicate the sensory and tactile conditions of live welding. The hybrid approach, sequencing VR with authentic practice, proved most effective, improving skill transfer, reducing material waste, and optimising instructor time.

The findings reinforce experiential learning theory by positioning VR as a preparatory stage that accelerates readiness for live tasks and apply diffusion of innovations theory to identify adoption drivers such as relative advantage, compatibility, and trialability. Practically, the results highlight the need for alignment with industry standards, targeted instructor training, and careful sequencing with real-world application. This approach supports the UAE's vocational education modernisation goals while preserving the authenticity essential to skilled trades training.

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