Virtual Learning Environment Design for Industrial Production Training based on Gamification: A Case Study in Cable Manufacturing

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Abstract. Industrial production is characterized by high levels of risk, making pre-job training for employees crucial. However, pre-job training itself is not without risks. The complexity of equipment often leads to improper operations, which can result in accidents causing personal injuries and property losses. Therefore, it is imperative for manufacturing enterprises to identify a suitable method for pre-job training. This study, based on gamification learning theory, proposes an interactive virtual environment for pre-job training, using a fiber-optic cable manufacturing company as an example. In this virtual environment, employees can operate digital models of fiber-optic production equipment. The study employs the instant feedback mechanism from gamification learning to enhance learning efficiency and quality. Additionally, this approach allows employees to learn in a safe virtual setting, avoiding accidents while mastering the operational standards of the equipment and the procedures for handling emergency events. The findings of this study offer a novel perspective and method for pre-job training in industrial manufacturing enterprises.

Keywords: Gamification; Pre-job Training; Interactive Technology; Virtual Learning Environment; Instant Feedback.

1 Background and Introduction

Industrial pre-job training is essential for product quality, process efficiency, and plant safety, yet conventional manuals, schematics and videos provide only abstract knowledge that learners struggle to translate into safe motor routines [1]. Because live equipment is dangerous, one trainee mistake can trigger cascading failures; hence factories must find safer, faster ways to build operator competence [2]. This study proposes a gamificative training framework for manufacturing plants. Using a cable plant as a testbed, researchers captured stakeholder requirements, linked a commercial game engine to high-fidelity physics models, and embedded adaptive difficulty, spatial quests

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and real-time safety scoring. The resulting prototype lets operators rehearse high-risk tasks without consequences while preserving the sensorimotor fidelity needed for safe transfer to the shop floor.

2 Literature Reviews

2.1 Demands in Pre-job Training in Cable Manufacturing Industries

Fiber-optic cable production demands pre-job training that fuses technical skills, safety protocols, process discipline and managerial compliance, with safety paramount: the complex, multi-subsystem machinery must be handled at micro-level precision to avert cascading failures that endanger lives and capital, forcing companies to invest heavily so novices fully internalize safe operation and emergency response before entering the real plant [3].

Current training is fragmented: curricula, instructors and mock-ups are scattered across departments, producing conflicting "truths" [4]; the master-apprentice model fossilizes errors, live drills are risky under high-temp and pressure conditions, and paper tracking plus 24/7 shifts block real-time analytics and synchronous classes. Turnover and slide-heavy lectures further erode effectiveness [5].

Fragmented training can be resolved by codifying tacit knowledge into unified, level-based curricula delivered via a lightweight desktop/mobile safety-simulation platform [6]. Critical processes such as drawing, coloring, chemical spills are broken into interactive micro-scenarios where trainees spot hazards, rehearse countermeasures and watch consequence models on any PC or smartphone. A cloud physics engine returns instant risk scores and pushes micro-learning video patches, while the backend aligns each learner's path with the single corporate standard, enabling rapid "learn-test-adapt" cycles that can mass-produce certified operators within required timelines [7].

2.2 Impacts from Gamificative Environment to Pre-job Training

Gamification exploits curiosity to lift task quality and completion [8]; instant feedback eclipses delayed grading, while achievement loops deliver micro-credentials for iterative mastery [9]. Virtual twins shield high-value plant: real risk is replaced by faithful alarms and consequence models, and penalty loops with adaptive cues refine motor memory at each learner's pace without endangering staff or assets [10].

Unity and Unreal supply turnkey physics/rendering pipelines for rapid 3D/VR integration [11]. Videos, infographics or haptic cues anchor to workstations while cloud profiles spawn "one-scene-per-trainee" arenas that evolve with each user, letting certification run 24/7 [12]. Cross-device sensing translates body, hand, face and gaze data into real-time avatar control, dissolving the physical-synthetic boundary for seamless human-computer symbiosis (see Fig. 1).

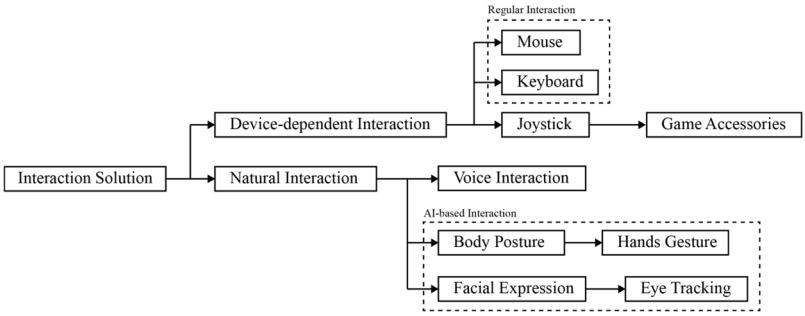

Fig. 1. Classification of Interaction Solutions

Marker-free mocap maps operators' finger moves to a gamificative digital twin of the fibre line; trainees handle photorealistic buttons and safety gear via avatars, getting instant feedback from success keeps the line running, errors trigger graded incident drills that build hazard sense without risk [13]. Industry favors cheaper desktop/mobile VR over costly full-immersion headsets, reserving the latter for cases where embodied interaction justifies the expense (see Fig. 2).

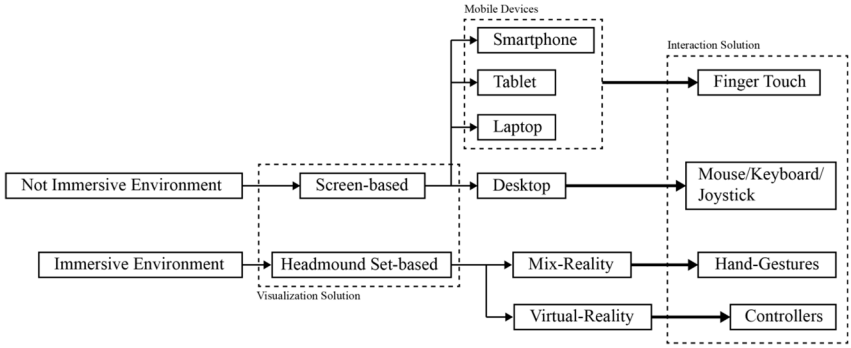

Fig. 2. Immersive Environment with Visualization and Interaction Technologies

3 Research Design

The question of this research is how pre-job training within optical-fiber manufacturing enterprises can be improved. The aim of this research is to develop and empirically test a gamificative training system that enables new employees to master safe equipment operation in a risk-free environment. The objectives of this research are: 1) What are the specific needs and pain-points of optical-fiber manufacturers in their current pre-job training programmes? 2) Which gamification theories and interaction technologies have proven effective for procedural-skills training? 3) How, and to what extent, can a gamificative environment enhance pre-job training outcomes in optical-fiber production?

A mixed-methods appoarch is adopted in this research. Objective 1 and 2 are addressed through literature review to make the exploration, while objective 3 is tackled via design intervention to make the assessment.

4 Design Intervention

A lightweight VR prototype gamifies pre-job safety training: bite-sized content of normal/ emergency steps are pinned to each virtual bench (see Fig. 3), while full-scale twins of drawing-line machines with working Human Machine Interfaces (HMIs) let trainees practice. The prototype can run on any office PC; modules unlock "Next" only after completion.

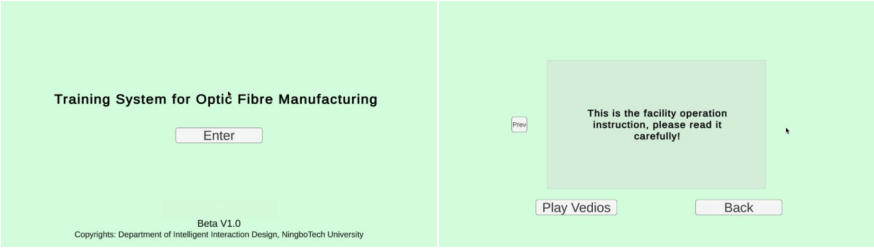

Fig. 3. Text and Video Instructions of the Training

A functional prototype for the gamificative virtual learning environment (see Fig. 4), consists of two tightly coupled C#-scripted Unity subsystems: an avatar-control layer that handles WASD locomotion, mouse-look inspection, and continuous proximity tracking to fiber-drawing twins, triggering contextual cues like tooltips, haptics, or permission gates; and a digital-equipment manipulation layer that enables interaction with the virtual plant.

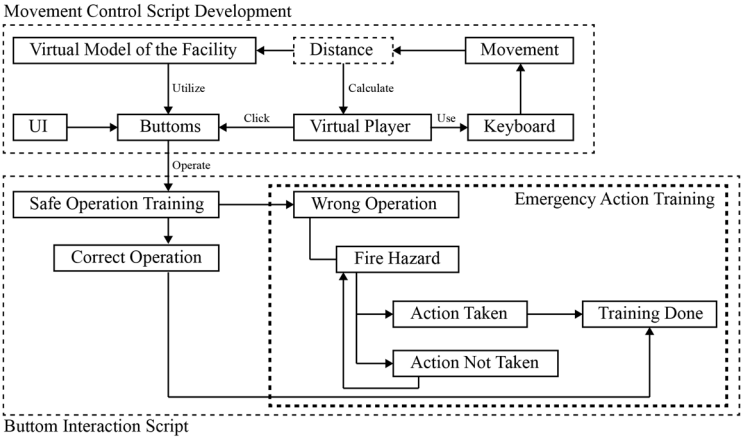

Fig. 4. Design of the Movement Module and Interaction Module

A proximity-triggered UI-button interface was implemented for stable, usable evaluation: when the avatar's Euclidean distance to a digital twin drops below a set threshold, a semitransparent three-button panel (clockwise, counter-clockwise, emergency stop) spawns at the object's screen centroid and is actuated with a left-mouse click via Unity's EventSystem (see Fig. 5), while model fidelity is capped at Level of Detail 200 (LOD 200) to keep mid-range workstations real-time .

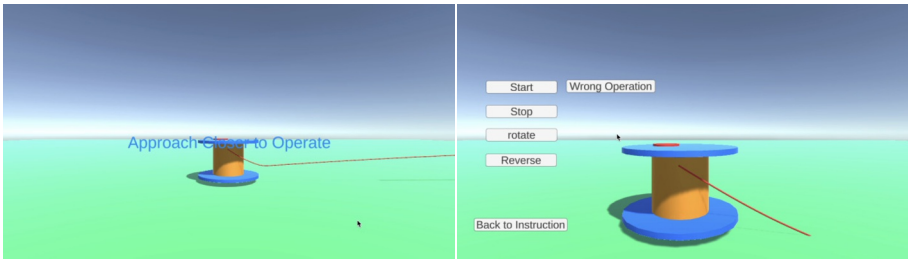

Fig. 5. UI of the Gamificative Training Environment

The prototype trains emergency fire-suppression: erroneous inputs instantly ignite an escalating particle fire whose flames, smoke and heat-shimmer provide feedback; trainees must follow branching prompts to select extinguishers or hit the emergency stop, and only the correct multi-step sequence extinguishes the blaze, otherwise the fire resets the scenario, after which a proficiency report is issued.

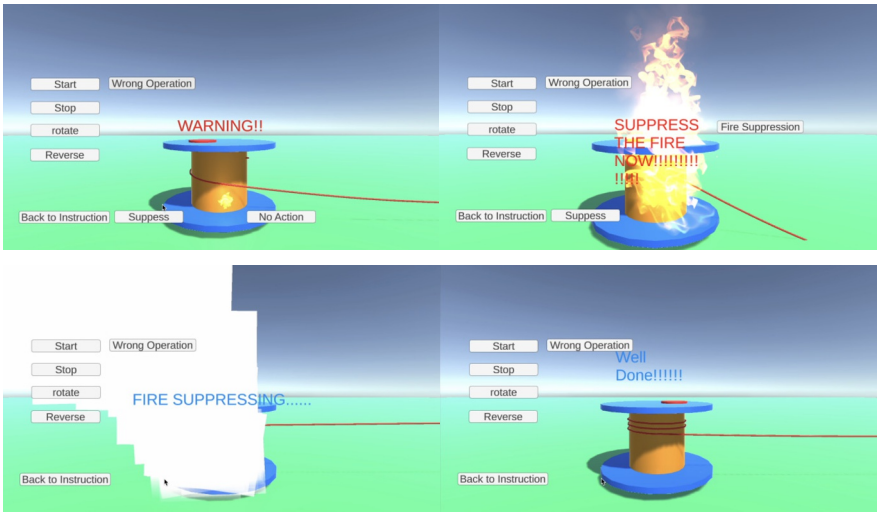

Fig. 6. Fire Hazard Training in the Gamificative Environment

(Fig. 6) depicts the drill sequence. Left above: an error ignites a fire and a red "WARNING"; right above: inaction makes flames, smoke and alerts intensify; left below: the correct steps activate suppression, display "FIRE SUPPRESSING"; right below: once extinguished, confirm completion.

5 Discussion

Purpose-built for fiber-plant safety training, the prototype lets novices rehearse fires, leaks, or trips without risk, cost, or intimidation; it flags errors instantly, offers real-time guidance, and outputs quantified proficiency scores to boost both efficiency and quality (see Fig. 7).

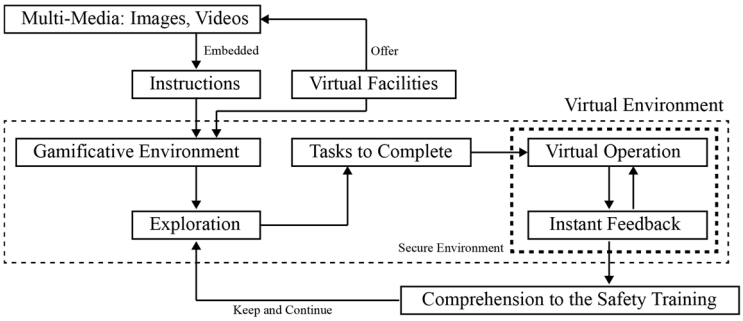

Fig. 7. Impacts from Gamificative Environment to Safety Operation Understandings

Gamificative training excels with millisecond feedback that detects, diagnoses and corrects every learner action, replacing the lag of master-apprentice setups. Multimodal cues such as text, video, audio, haptic present tasks simultaneously, embedding routine and emergency know-how in one mental model (see Fig. 8). Interaction drives learning: keystrokes become virtual-equipment moves that lock correct sequences into memory, while avatar navigation of the digital twin offers an egocentric, risk-free reconnaissance of the plant, merging physical and virtual realms for seamless pre-job safety training.

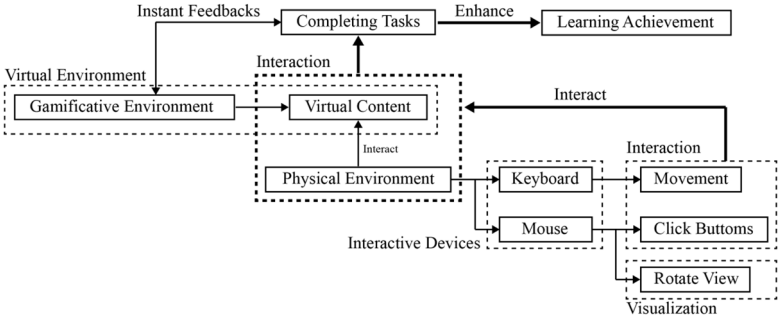

Fig. 8. Impacts from Interactive Technologies to Learning Performance

In optical-fiber production training, a gamificative learning platform first uses visualization to let trainees explore a virtual replica of the shop floor, forming a mental model of its layout and equipment, and then layers on interaction technologies for locomotion and digital-twin manipulation; this visual scaffold supports adaptive, multimodal content and feedback that dynamically adjusts to each user's proficiency to maximize mastery.

6 Conclusion

This research designed and developed a gamificative, zero-risk simulator that lets optical-fiber trainees rehearse authentic operations and emergencies; lab tests showed faster, better-retained skills and higher motivation. The work advances theory by unifying risk-free practice with high-fidelity transfer in hazardous production lines and offers industry a modular, extensible codebase for rapid, low-cost deployment across plants.

7 Limitation and Future Research

The limitation of this research is that exclusive virtual training risks a sim-to-real gap such as oversimplified physics, user detachment, and reversible risk-taking erode on-site quality. Hybrid training is therefore essential. The current prototype covers only basic fire drills and was assessed with non-operators in a laboratory setting. Future work will focus on: 1) expand gamificative modules to encompass all safety-critical and routine fibre-plant tasks, incorporating haptics, adaptive difficulty, and narrative scenarios; 2) achieve 1:1 digital-twin fidelity through BIM integration and live sensor feeds; 3) conduct a powered, randomized field trial to quantify real-world improvements in learning, safety, and user experience.

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Disclosure of Interests

The authors have no competing interests to declare that are relevant to the content of this article.

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