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VIRTUAL REALITY-BASED IMMERSIVE LEARNING IN TECHNICAL EDUCATION: THE "TECH-VR LAB" FRAMEWORK

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Annotation

This article presents the development and educational impact of Tech-VR Lab, a new Virtual Reality-based system that transforms technical and engineering training into an immersive, interactive experience. Rather than relying on expensive physical laboratories with limited equipment and strict safety constraints like most traditional methods, Tech-VR Lab uses a scenario-based approach that places students inside fully simulated industrial environments and automatically tracks their practical performance. Developed with Unity, WebXR, and Three.js, the platform offers a cross-platform, low-cost solution that runs directly in any modern web browser or VR headset, removing the need for costly hardware. The study highlights how this technology improves the quality of technical education for engineering students, explains the gesture-to-simulation interaction logic, and explores the future of immersive digital learning in Uzbekistan.

Keywords: Virtual Reality, Immersive Learning, Tech-VR Lab, Technical Education, Unity, WebXR, 3D Simulation, Engineering Training.

Introduction

In today's rapidly evolving technological world, modernizing technical education remains one of the biggest challenges. Engineering and vocational students often face serious difficulties when accessing high-cost laboratory equipment, limited practice hours, and safety risks when working with complex machinery. Traditional teaching methods are usually not enough, and physical lab sessions are not always available when needed. The Tech-VR Lab project was created as a technological solution that uses Virtual Reality and 3D Simulation to convert abstract technical concepts into hands-on, risk-free practical experience. Focused on the Uzbek educational context while using widely recognized international engineering standards, the system aims to make high-quality technical training easier and more equal for every student.

Beyond Traditional Labs: An Immersive Approach. Most existing engineering courses utilize "physical laboratory rotation," where students take turns using a limited number of devices under strict time constraints. While effective, this method is slow, expensive, and does not give every learner sufficient hands-on practice. Tech-VR Lab introduces a Scenario-Based Immersive Model. By recreating entire industrial environments — such as an "Electrical Workshop" (Elektr ustaxonasi), a "CNC Machine Room" (CNC bo'limi), and a "Power Substation" (Elektr podstansiyasi) — the system allows for more natural and experiential learning. This approach reduces the equipment burden on universities and significantly accelerates the development of real practical skills.

Technical Architecture and Implementation

The system is built on a modern web-based and cross-platform stack to ensure maximum accessibility:

- **3D Environment:** Utilizing Unity Engine and Three.js, the system renders detailed industrial scenes with realistic physics, lighting, and material properties.
- **Interaction Logic:** To ensure real-time performance even on low-end devices, we implemented optimized WebXR controllers that allow students to grab, rotate, assemble, and operate virtual equipment using motion controllers or smartphone sensors.

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- **Performance Tracker:** A unique feature of this project is the Learning Analytics Module. Every action performed by the student — from connecting wires to operating a lathe — is recorded in a temporary array. When a task is completed, the system compiles these actions into a structured performance report and triggers automated feedback through the Web Speech API.

Developing a VR-based training platform for Uzbekistan involves several difficulties, especially the limited availability of high-end VR headsets in regional universities. Tech-VR Lab solves this issue by:

1. Using WebXR as a base for delivering VR content directly through standard browsers.
2. Adapting simulations to work on low-cost mobile VR (smartphone + Cardboard holder).
3. Offering a simple web-based solution that works on any device (computers, Android, and iOS) through a regular browser link, avoiding the need to install separate applications.

The Future of Immersive Education

In the coming stages, Tech-VR Lab will move from rule-based interaction logic to advanced AI-driven instructors, particularly LLM-powered virtual mentors, which will better handle complex and dynamic student questions in real time. Future development will focus on:

Integration: Connecting the system to national education platforms (such as HEMIS) and university LMS systems like Moodle.

Crowdsourced Content: Enabling instructors to contribute their own simulation modules to help create the first large-scale digital library of Uzbek engineering scenarios — covering textile machinery, energy infrastructure, and agricultural technology.

Conclusion

Tech-VR Lab represents a transformative step in making high-quality technical education accessible to everyone. By combining real-time 3D simulation with an intelligent learning analytics engine, we have moved beyond simple observation toward true experiential mastery. As VR technology continues to evolve, tools like Tech-VR Lab will ensure that no engineering student is left behind in our increasingly digital industrial world.

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