

DESIGN-BASED RESEARCH

Immersive Virtual Reality Laboratory Simulations with AI-Driven Pedagogical Guidance for High-Risk Chemical Synthesis

Joko Susilo, Farida Hanum, Thomas Becker

1. Dept. of Chemical Education & Virtual Environments, Universitas Tadulako; 2. Immersive Media Research Lab; 3. Virtual Reality Pedagogical Initiative.

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Abstract

A three-phase design experiment testing intelligent conversational avatars guiding students through volatile titration procedures in VR. Learner laboratory safety protocol compliance improved by 89% in subsequent physical lab tests.

Keywords: Virtual Reality, Chemistry Education, AI Pedagogical Agent, Lab Safety, Hazardous Synthesis

1. Introduction

Exposing undergraduate chemistry students to explosive, exothermic, or toxic chemical syntheses is severely constrained by laboratory safety considerations and expensive waste protocols. 6-DOF Virtual reality environments augmented by intelligent agent guidance bridge this high-risk pedagogical gap.

2. Method

A design-based research methodology deployed an interactive VR synthesis suite paired with an intelligent non-player character (NPC) laboratory instructor across 180 undergraduate chemistry students prior to physical chemical laboratory exams.

3. Results and Discussion

Students rehearsing in the VR environment committed 89.2% fewer critical safety errors (spill management, fume hood ventilation compliance) during physical benchmark syntheses, exhibiting heightened spatial procedural confidence.

4. Conclusion

Immersive 6-DOF VR simulations paired with conversational AI tutors establish cognitive muscle memory, mitigating risks while accelerating procedural laboratory competency in chemical sciences.

Declarations

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Conflicts of Interest: The authors declare that they have no competing financial or personal interests.

Data Availability: The dataset and analysis matrices associated with this study are available in the public data repository.

Author Contributions: All authors contributed equally to conceptualization, investigation, formal analysis, and manuscript preparation.

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