Abstract Title
EXPLORING VIRTUAL REALITY SIMULATION LABS IN UNDERGRADUATE SCIENCE EDUCATION

Keywords:
virtual reality; simulation labs; undergraduate science education; laboratory teaching; STEM education

Background & Context

Undergraduate science students often struggle to learn new laboratory activities, and limited laboratory time can reduce opportunities for hands-on learning and safe practice. Laboratory accidents are often associated with insufficient practical experience and safety knowledge (Nasrallah et al., 2022). Virtual reality (VR) offers high-fidelity, repeatable practice in a safe environment and aligns with experiential learning approaches that connect experience, reflection, conceptualization, and experimentation (Wijnen-Meijer et al., 2022).

Aim / Research Question(s)

This study aimed to evaluate undergraduate students' perceptions, clarity, confidence, and perceived complexity of laboratory experiments after exposure to VR and video-based laboratory materials. We also examined whether students' responses differed by science major or mode of exposure.

Methods / Intervention

We conducted a Phase 1 convergent mixed-methods pilot study in undergraduate Biology and Chemistry laboratory courses at Khalifa University, including BIOL 111/112/211 and CHEM 311/352. Real laboratory sessions were recorded using an Insta360 camera and edited into 2D desktop videos and immersive 360° VR simulations, following the use of immersive VR laboratory recordings described in recent laboratory education work (Tandon et al., 2024). Students experienced the materials through 2D-only, 3D-only, or combined 2D+3D conditions. Survey data were collected from 92 unique post-survey undergraduate students across multiple majors, with matched pre-post scale analyses available for 68 students and VR reflection analyses available for 20 students. Quantitative data were collected using a 14-item Likert-scale survey, and open-ended comments were analyzed thematically to explore students' experiences with the laboratory videos and VR materials.

Results / Findings

The survey scales showed acceptable internal consistency, with Cronbach's alpha values of approximately 0.70–0.84 across scales. Students' mean clarity/confidence scores increased significantly from 3.34 to 3.85, $t(67) = 5.33$, $p < .001$, Cohen $dz = 0.65$, while perceived complexity decreased significantly from 2.81 to 2.43, $t(67) = -5.06$, $p < .001$, Cohen $dz = -0.61$. VR reflection scores did not change significantly, likely due to the smaller matched sample and high baseline scores. Between-group analyses suggested that the 3D-only condition was associated with lower perceived complexity and stronger VR reflection/experience than the 2D+3D condition. At the same time, no statistically significant differences were observed among students from different science majors. Qualitative analysis revealed three key themes: enhanced clarity and confidence, reduced perceived complexity of the material, and a consistently positive impact among science majors, alongside practical suggestions on motion comfort, camera angles, subtitles, pacing, audio, and interactivity.

Conclusion & Implications for Teaching Practice

VR and 2D laboratory recordings were found to be feasible and acceptable adjuncts to undergraduate science laboratory teaching. These results are consistent with evidence that VR

experiential learning can support undergraduate learning outcomes and that biology students may view immersive VR as a valuable and practical learning tool (Chen et al., 2024; Majewska & Vereen, 2023). Educators can use VR lab recordings as a scalable pre-lab strategy to support clearer understanding, greater confidence, and safer preparation, while paying careful attention to ergonomic comfort, camera stability, visual clarity, and interactivity. Future work should integrate VR into regular laboratory curricula and use validated laboratory skill checklists to evaluate whether perceptual gains translate into measurable psychomotor performance in laboratory settings (Hunt et al., 2012).

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