

ORIGINAL PAPER

Inquiry-Based Learning and Virtual Laboratory Simulations: A Longitudinal Study of Secondary School Chemistry Competency

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Abstract

A two-year comparative cohort design (N=1,420) measuring conceptual retention in chemical equilibrium using interactive virtual laboratories. Results indicate statistically significant reductions in alternative misconceptions ($p < 0.001$).

Keywords: Virtual Laboratories, Inquiry-Based Learning, Chemical Equilibrium, Conceptual Understanding, Longitudinal Design

1. Introduction

Abstract chemical phenomena such as dynamic equilibrium and reaction kinetics often engender persistent misconceptions among high school learners. While physical laboratories provide hands-on tactile engagement, virtual simulations enable iterative micro-level experimentation without resource constraints.

2. Method

A two-year randomized controlled trial evaluated 1,420 students assigned to either traditional wet-lab instruction or a blended inquiry-simulation program. Assessment was conducted via a validated Two-Tier Chemical Equilibrium Diagnostic Instrument administered across four test points.

3. Results and Discussion

Mixed-model ANOVA showed significant main effects for instruction modality ($F(1, 1418) = 112.4, p < 0.001, \eta^2 = 0.18$). Misconceptions concerning Le Chatelier's principle decreased by 64% in the blended simulation cohort, with conceptual retention remaining stable over 12 months.

4. Conclusion

Blended virtual laboratories facilitate deeper mental modeling of invisible sub-microscopic particle dynamics, outperforming standalone physical labs in promoting long-term conceptual retention.

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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