

ARTIFICIAL INTELLIGENCE–BASED SIMULATIONS FOR LABORATORY SAFETY IN CHEMISTRY EDUCATION

Pashayeva A. A.

Baku State University, Baku, Azerbaijan

Pasayeva-1969@mail.ru

This article explores how AI-based simulations can strengthen laboratory safety in chemistry education by enabling students to practice hazard recognition, safe decision-making, and correct procedural behavior in risk-free virtual environments. The paper outlines a didactic framework for integrating AI-driven scenarios into chemistry lessons and discusses how simulation-based training can support safety culture, formative assessment, and competency development.

Laboratory work is central to chemistry learning, yet safety instruction in many schools is often limited to rules, brief briefings, or passive checklists. Such approaches may not reliably develop stable safety habits, especially when schools face constraints such as limited equipment, crowded classes, or reduced lab time. AI-based simulations are increasingly relevant because they allow repeated practice with realistic hazard scenarios, provide immediate feedback, and help teachers monitor safety-related competencies. Therefore, investigating this approach is timely for modernizing chemistry teaching methodology and improving student safety outcomes. The aim of the study is to justify the methodological value of AI-based simulations in teaching laboratory safety in chemistry and to define how these tools can be used to develop students' safety competencies—particularly hazard identification, risk-aware decision-making, and adherence to laboratory procedures—within the structure of secondary chemistry lessons. The novelty of the article lies in interpreting AI-based simulations not merely as digital demonstrations, but as a didactic mechanism for shaping laboratory safety culture through adaptive scenarios, individualized feedback, and competency-oriented assessment. The study proposes a methodology-focused model that links typical chemistry lab risks (chemical burns, toxic vapors, improper heating, glassware handling, waste disposal) to targeted learning outcomes and observable behavioral indicators. In addition, it highlights how simulation analytics can be used to diagnose common safety misconceptions and track progress over time. Practically, the proposed approach offers chemistry teachers an implementable pathway to teach safety more effectively even when full laboratory access is limited. AI-based simulations can be used for pre-lab preparation, safety certification before experiments, differentiated support for students with varying readiness, and formative evaluation using clear rubrics. The framework can also inform teacher training courses and the development of school-level safety modules aligned with competency-based curricula [1, 2].

The article concludes that AI-based simulations have strong potential to improve laboratory safety in chemistry education by transforming safety instruction from passive memorization into active, repeated, and feedback-rich practice. When methodically integrated into lesson design, simulations can enhance students' hazard awareness, strengthen responsible laboratory behavior, and support teachers in monitoring safety competencies. As a result, AI-based simulation pedagogy can contribute to a more sustainable and resilient laboratory safety culture in secondary chemistry teaching.

References

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