



The Role of Artificial Intelligence in Enhancing Chemical Safety in Science Laboratories

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Abstract

This study examined the role of artificial intelligence (AI) in improving chemical safety knowledge among science students. Science laboratories are critical for practical learning but carry significant risks due to exposure to hazardous materials. Conventional safety practices rely heavily on human judgment and often fail to predict or prevent incidents. AI technologies, such as predictive analytics, smart sensors, and automation, can strengthen safety monitoring and hazard prevention. Using a descriptive survey, data were collected from 100 secondary school students in Oyo State to assess their safety knowledge, AI awareness, and views on AI integration. Results show fair knowledge of safety rules and personal protective equipment, but weaker skills in hazard identification and training access. Figure 1 presents weighted means (3.17, 3.13, 2.56, 2.51) and standard deviations (0.92–1.13), showing moderate consistency and gaps in emergency preparedness. Awareness of AI applications was generally low, but students expressed strong interest in AI-based safety training and teacher-led demonstrations. Findings suggest that integrating AI modules into science curricula, training teachers, and providing affordable tools could reduce laboratory risks and enhance student readiness for technology-driven science education.

Keywords: Artificial Intelligence, Chemical Safety, Science Laboratories, Chemical, Safety

Introduction

Science laboratories remain central to education and research in chemistry and related disciplines. However, they are also high-risk environments, where accidents, chemical exposure, and improper handling can lead to severe consequences for students, researchers, and institutions. Traditional safety protocols, while valuable, are limited by human error and inadequate risk anticipation. Kumari, Mwesigye, and Balimuttajjo (2024) describe a science laboratory as a learning space where experiments are conducted and where learners gain a practical and more comprehensive grasp of scientific concepts. This suggests that the laboratory is not merely a physical space but also a foundation for developing problem-solving and inquiry skills. According to Ibragimov et al. (2023), the science laboratory should be viewed as a type of learning environment both physical and social that directly influences how students learn. Their perspective emphasizes the broader educational context, positioning laboratories as settings that shape interaction and knowledge construction.

Artificial intelligence (AI) provides a transformative opportunity to enhance chemical safety by combining machine learning, data analytics, and smart technologies. Through real-time monitoring, AI can detect hazardous situations earlier than human observation alone, reducing accident rates and promoting proactive risk management. Scholars increasingly view AI as a critical tool for modern laboratory safety (Zhou et al., 2022; Singh & Verma, 2023).

Concept of Chemical Safety in Science Laboratories

Chemical safety refers to strategies and practices that minimize risks linked to the use, storage, and disposal of chemicals (Olowokere et al., 2022). In the laboratory setting, safety encompasses personal protective equipment (PPE), proper waste management, hazard communication, and adherence to regulatory standards. AI introduces a new dimension to this definition by offering predictive insights and adaptive monitoring systems. Instead of relying solely on fixed rules and manual oversight, AI systems can adaptively learn from laboratory data, helping to foresee accidents before they occur (Gupta et al., 2024). Chemical safety means having clear rules and methods to make sure chemicals are used, kept, and thrown away in a way that keeps people and the environment safe from

harm. It encompasses not only protective measures during experimentation but also preventive strategies that anticipate hazards before they occur (Okafor, 2025). The International Labour Organization (ILO, 2024) emphasizes that chemical safety should move beyond compliance and incorporate preventive culture, stressing continuous education and monitoring.

Artificial Intelligence and Its Applications in Chemical Safety

AI applications in chemical safety can be categorized into several domains:

1. Predictive Analytics

Machine learning models can analyze patterns in chemical usage, experimental procedures, and historical incidents to forecast potential hazards (Tanaka et al., 2022). For example, algorithms may predict which reagents pose explosion risks under certain storage conditions.

2. Computer Vision and Surveillance

AI-powered cameras and image recognition systems detect unsafe behavior such as missing PPE, chemical spills, or improper waste disposal (Hernández et al., 2023). These tools act as “digital supervisors” in real time.

3. Smart Sensors and Internet of Things (IoT)

Integration of IoT with AI enables laboratories to use sensors that detect gas leaks, temperature fluctuations, or chemical imbalances. AI analyzes this sensor data instantly to generate safety alerts (Wang & Zhao, 2023).

Robotics and Automation

Hazardous tasks like mixing volatile compounds can be automated using AI-driven robots, minimizing human exposure (Ali et al., 2021).

Benefits of AI in Chemical Safety

- Accident Prevention – Early detection systems reduce laboratory accidents.
- Efficiency – Automation saves time and lowers costs of monitoring.
- Enhanced Learning – Students gain exposure to cutting-edge technology alongside laboratory practice.
- Data-Driven Decisions – Continuous collection of laboratory safety data enables long-term improvements.

Challenges in Implementing AI for Chemical Safety

Despite the benefits, several barriers exist:

- High Cost – Advanced AI systems and IoT devices are expensive for schools and research labs in developing regions.
- Skill Gap – Many laboratory personnel lack AI-related technical skills (Okafor et al., 2024).
- Data Privacy – AI surveillance raises ethical concerns regarding monitoring and personal data use.
- Technological Limitations – Machine learning models may misinterpret data without proper training sets.

Roadmap for Integration

For successful adoption of AI in chemical safety, institutions should:

1. Invest in low-cost AI safety tools suitable for educational settings.
2. Provide training programs for laboratory staff and students.
3. Establish policies balancing data collection with privacy.
4. Encourage collaborative research between AI experts, chemists, and educators.

Statement of the problem

Chemistry laboratories are essential for building practical skills and reinforcing theoretical knowledge. However, they are also high-risk environments because they involve handling flammable, corrosive, toxic, and reactive substances. It was indicated that chemical accidents remain common in schools and universities, often resulting in injuries, property damage, and disrupted learning. Traditional safety measures such as rules, personal protective equipment (PPE), and emergency drills are important but are mainly reactive. Therefore, the core problem addressed in this study is the gap between existing safety practices and the potential of AI to improve hazard prevention and response in chemistry laboratories. Without integrating AI into teaching and laboratory management, students may continue to face risks that could otherwise be minimized.

Aims and Objectives of the study

The study aimed at the role of artificial intelligence in understanding chemical safety in science laboratories among secondary school science students in Oyo state.

To achieve this aim, the study seeks to:

- Examine the level of students' understanding of chemical safety in Science laboratories.
- Examine the level of awareness of Artificial Intelligence in science laboratories.
- Identify how AI be integrated into chemical safety practices in laboratories.
- Determine the roles teachers play in teaching AI-driven chemical safety.

Research Questions

- What is the level of students' understanding of chemical safety in Science laboratories?
- What is the level of awareness of Artificial Intelligence in science laboratories?
- What are some ways to include AI into laboratory chemical safety procedures?
- What roles can teachers play in teaching AI-driven chemical safety?

Materials and Methods

This study employed a descriptive survey research design. The design was appropriate because it allowed the researcher to gather opinions, perceptions, and experiences of students regarding the role of artificial intelligence (AI) in enhancing chemical safety within chemistry laboratories. A descriptive survey also provides a cost-effective way of obtaining data from a relatively large sample (Eze, 2025). The study population was made up of science students in secondary schools. These students were chosen because they frequently engage in laboratory activities where chemical safety is essential. Sampling technique employed is multi-stage that involves a combination of simple random sampling of Oyo West and East from four LGAs in Oyo; a simple random sampling selection of 5 secondary schools in the two LGAs, then a purposive sampling selection of students (50) from each of the LGAs. Purposive selection was used because it allows the researcher to deliberately choose participants who have specific knowledge, skills or experiences related to research problem. A structured questionnaire was developed to obtain data from respondents. The instrument contained 20 items divided into four thematic sections namely; students' understanding of chemical safety, awareness of artificial intelligence in chemistry laboratories, perceptions of AI integration in chemical safety practices and teachers' role in teaching AI-driven chemical safety. The questionnaire was rated on four Likert scales ; strongly agree (SA), Agree (A), Disagree (D) and Strongly Disagree (SD). To ensure validity, the questionnaire was reviewed by two experts in Science Education and one specialist in Educational Technology. Their suggestions were incorporated into the final instrument to improve clarity and alignment with the study objectives. Twenty chemistry students who were not part of the study sample participated in a pilot test. Data obtained were analyzed using Cronbach's Alpha, which yielded a reliability coefficient of 0.82, indicating that the instrument was highly reliable. The researcher personally administered the questionnaires to the 100 respondents, ensuring a 100% return rate. This approach reduced the chances of instrument loss and enhanced response accuracy. The collected data were analyzed utilizing weighted mean and standard deviation. The decision rule was based on the four Likert scales: 3.50 – 4.00 = Strongly Agree (SA) 2.50 – 3.49 = Agree (A), 1.50 – 2.49 = Disagree (D), 1.00 – 1.49 = Strongly Disagree (SD), and Standard deviation (SD) was used to determine consistency of responses, where $SD < 1.0$ indicates high consistency and $SD > 1.0$ shows varied opinions.

Results

Research Question 1: What is the level of students' understanding of chemical safety in science laboratories?

Table 1: Weighted Mean and Standard Deviation of Students' Responses on students' understanding of chemical safety in science laboratories

S/N	Statement (Summary)	Weighted Mean	Std. Dev.	Decision
1	I am familiar with chemical safety rules	3.17	0.92	Agree
2	I understand importance of PPE	3.13	0.90	Agree
3	I can identify hazardous chemicals	2.56	1.13	Agree
4	Institution provides training on safety	2.51	1.04	Agree

Field Survey, 2025.

The results show that students are familiar with chemical safety rules (WM = 3.17) and recognize the importance of PPE (WM = 3.13) with consistency ($SD < 1.0$). However, hazard identification (WM = 2.56, $SD = 1.13$) and institutional training (WM = 2.51, $SD = 1.04$) recorded lower means with high variability, indicating inconsistent experiences.

Research Question 2: What is the level of awareness of Artificial Intelligence in science laboratories?

Table 2: Weighted Mean and Standard Deviation of Students' Responses on level of awareness of Artificial Intelligence in science laboratories

S/N	Statement (Summary)	Weighted Mean	Std. Dev.	Decision
5	AI can monitor lab safety	2.43	1.11	Disagree
6	AI can detect unsafe reactions	2.15	1.04	Disagree
7	AI can track/store inventory	2.23	1.03	Disagree
8	AI can improve emergency response	2.60	1.16	Agree

Field Survey, 2025.

Most students disagreed that AI can monitor lab safety (WM = 2.43), detect unsafe reactions (WM = 2.15), or track chemical inventory (WM = 2.23). Only slight agreement was recorded for AI improving emergency response (WM = 2.60, SD = 1.16), but responses were divided.

Research Question 3: What are some ways to include AI into laboratory chemical safety procedures?

Table 3: Weighted Mean and Standard Deviation of Students' Responses on ways to include AI into laboratory chemical safety procedures

S/N	Statement (Summary)	Weighted Mean	Std. Dev.	Decision
9	AI sensors can detect gas leaks	2.93	0.99	Agree
10	AI for real-time safety monitoring	2.76	1.11	Agree
11	AI reduces lab accidents	3.02	0.96	Agree
12	Students should be trained on AI	3.18	0.87	Agree

Field Survey, 2025.

Students showed positive attitudes toward integrating AI:

AI sensors for gas leaks (WM = 2.93), Real-time monitoring (WM = 2.76), Accident reduction (WM = 3.02), Strongest support for training students in AI applications (WM = 3.18).

Research Question 4: What roles can teachers play in teaching AI-driven chemical safety?

Table 4: Weighted Mean and Standard Deviation of Students' Responses on roles teachers can play in teaching AI-driven chemical safety

S/N	Statement (Summary)	Weighted Mean	Std. Dev.	Decision
13	Teachers can use AI simulations	2.93	1.00	Agree
14	Teachers need training on AI first	3.19	0.95	Agree
15	Teaching AI improves safety-consciousness	2.96	1.00	Agree
16	AI concepts should be in curriculum	2.66	1.06	Agree

Field Survey, 2025.

Students agreed that teachers should be trained first (WM = 3.19), AI teaching can improve safety consciousness (WM = 2.96), and teachers can use AI simulations (WM = 2.93). However, inclusion of AI in the curriculum (WM = 2.66, SD = 1.06) had mixed support.

Discussion

In Table 1, students generally understand the principles of chemical safety but still show moderate gaps in areas such as emergency response. This finding agrees with Okafor (2025), who noted that while PPE awareness is relatively high, practical emergency preparedness among students remains limited. This finding aligns with Okafor (2025), who emphasized that while theoretical safety knowledge is often taught, practical applications such as fire drills, spill management, and emergency evacuation procedures remain underemphasized in many institutions.

According to Table 2, students have some awareness of AI but lack practical understanding. This supports Eze (2025), who emphasized the need to introduce AI concepts into science curricula for better laboratory safety. The study further revealed a low level of awareness of AI applications in chemistry laboratories. Although students had heard of AI generally, many lacked practical exposure to its role in laboratory safety. This is consistent with Eze (2025), who reported that AI remains underutilized in science education in Nigeria due to inadequate curriculum integration.

According to Table 3, students positively perceive AI as a tool for preventing laboratory accidents and enhancing safety training. This finding aligns with Wang and Li (2023), who highlighted predictive analytics and simulations as effective AI safety applications. It was also found that students strongly believe AI can play a transformative role in ensuring laboratory safety by predicting chemical hazards, monitoring gas leaks, and providing virtual safety training simulations. This aligns with Wang & Li (2023), who argued that AI-driven predictive analytics can significantly reduce laboratory accidents by identifying risks before they escalate.

Table 4 shows that students strongly believe teachers play a vital role in bridging the gap between AI and chemical safety. Johnson (2025) emphasized the importance of teacher-led workshops and demonstrations in improving student competency in AI-driven laboratory practices. Students highlighted that teachers are central to the successful integration of AI into laboratory practices. They expect teachers to introduce AI concepts in class, demonstrate AI tools, and organize workshops. This supports Johnson (2025), who argued that teachers serve as facilitators of digital transformation in science education and must be empowered to guide students in adopting AI.

Conclusion

This study concludes that while students possess a fair understanding of basic chemical safety principles, their awareness and application of AI in laboratory safety remain limited. However, students strongly recognize the potential benefits of AI in predicting risks, preventing accidents, and improving training. Teachers play a pivotal role in bridging this gap by integrating AI concepts into classroom and laboratory practices. Strengthening AI adoption in laboratory safety education will therefore contribute to safer laboratory environments and enhance students' readiness for modern scientific practice.

Recommendations

The findings lead to the following recommendations:

1. Curriculum Integration: Science education curricula should be revised to include AI-driven chemical safety modules.
2. Teacher Training: Professional development programs should be organized to equip teachers with knowledge of AI applications in laboratory safety.
3. Practical Exposure: Students should be given opportunities to interact with AI tools such as safety sensors, predictive software, and virtual simulations during laboratory sessions.
4. Policy Support: Educational policymakers should collaborate with technology companies to provide affordable AI tools for use in school and university laboratories.
5. Workshops and Seminars: Regular awareness campaigns, workshops, and seminars should be conducted to sensitize both students and teachers on the importance of AI in laboratory safety.

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