

Assessing Safety Status of Physical Infrastructure in Chemistry Laboratories: A Study of Public Colleges of Education in Ghana

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Abstract

This article examines the safety status of physical infrastructure in chemistry laboratories within public colleges of education in Ghana. As chemistry laboratories are critical environments for scientific education and experimentation, their safety standards are paramount to ensure both student and staff well-being. The study employs a comprehensive evaluation framework to assess the current safety status of chemistry laboratory physical infrastructure across several institutions. Key aspects analyzed include the availability, appropriateness, and maintenance of laboratory physical infrastructure, adherence to safety protocols, and the overall environment's compliance with international safety standards. The findings highlight significant areas of concern, including outdated physical infrastructure, insufficient safety measures, and inconsistencies in safety practices in the various colleges. Recommendations are provided to enhance safety standards, including increased investment in infrastructure, regular safety audits, and improved training for laboratory personnel. This research underscores the need for systematic improvements to safeguard the learning environment and ensure the effective conduct of chemistry education in Ghana's public colleges.

Keywords

Safety Standards, Physical Infrastructure, Chemistry Laboratories, Safety Protocols, Public Colleges of Education

1. Introduction

The pivotal role of science education in the socio-economic development of nations

is well recognized in literature, and Ghana is no exception to this global trend (Coccia, 2019: pp. 1-6). Science education is integral to the curriculum across educational systems, as it significantly impacts learners' ability to understand and apply scientific concepts to improve their living standards (Fauth et al., 2019; Kleickmann et al., 2016). The effectiveness of science education relies heavily on the quality of instruction provided by well-trained teachers and the implementation of a robust curriculum that fosters scientific inquiry and practical experience (Wrightson et al., 2016: pp. 109-121).

In Ghana, several interventions have been introduced to enhance learning outcomes in science education. These include the introduction of a new teacher licensure scheme by the National Teaching Council and the Ghana Education Service, as well as initiatives like the Differentiated Learning Initiative and Professional Learning Communities. A significant development was the implementation of a standard-based curriculum by the National Council for Curriculum and Assessment and Ministry of Education (NaCCA) (2019), aimed at setting clear educational standards and learning outcomes (Ministry of Education, 2019). This curriculum emphasizes the need for a conducive learning environment in science classrooms to support effective education and encourage students to engage with scientific concepts actively (Ministry of Education, 2020).

At the teacher education level, reforms such as the 2004 Educational Reforms and the Transforming Teacher Education and Learning (T-TEL) initiative have led to the upgrading of Teacher Training Colleges to degree-awarding institutions and the revision of curricula (Ministry of Education, 2017). These reforms aim to improve the quality of science and mathematics instruction by preparing pre-service teachers through comprehensive training in various science subjects, including chemistry.

1.1. Statement of the Problem

The effectiveness of science education for socio-economic development is profoundly influenced by the quality of teaching and the implementation of a robust curriculum (Coccia, 2019: pp. 1-6; Fauth et al., 2019; Kleickmann et al., 2016). In Ghana, recent educational reforms and initiatives, such as the introduction of a standard-based curriculum by the National Council for Curriculum and Assessment (NaCCA) and the Transforming Teacher Education and Learning (T-TEL) initiative, have aimed to enhance science education by upgrading Teacher Training Colleges and revising curricula (Ministry of Education, 2019; Ministry of Education, 2020; Ministry of Education, 2017).

Despite these efforts, there remains a critical issue concerning the adequacy and appropriateness of physical infrastructure and safety protocols in chemistry laboratories at Colleges of Education. The effective implementation of science curricula relies not only on the quality of instruction and curriculum design but also on the safety and functionality of laboratory environments where practical work is conducted. However, there is insufficient research focusing on the safety status of

these laboratories, which raises concerns about whether existing safety measures align with the curriculum's practical requirements and national safety standards.

Thus, the problem lies in the apparent gap between the expected standards of laboratory safety and the actual conditions in chemistry laboratories within Ghanaian Colleges of Education. This gap potentially undermines the quality of science education and poses risks to both students and staff. Addressing this issue is imperative to ensure that laboratory environments support effective learning and adhere to safety regulations.

1.2. Objectives of the Study

The study is guided by the following objectives:

- 1) To examine the safety status of physical infrastructure in chemistry laboratories at public colleges of education in Ghana.
- 2) To find out the gaps in the current safety measures in these laboratories and how they affect the quality of science education.

1.3. Research Questions

- 1) What is the safety status of physical infrastructure in chemistry laboratories at public colleges of education in Ghana?
- 2) What are the gaps in the current safety measures in these laboratories, and how do they affect the quality of science education and student safety?

1.4. Significance of the Study

Laboratory safety is an important and necessary part of chemistry teaching and learning. In fact, there can be no meaningful teaching and learning in a setting that is unsafe and insecure for both learners and teachers. A safe and secure chemistry laboratory environment must be maintained to facilitate effective teaching and learning.

The research aimed to provide insights to policymakers in science education regarding safety issues in the chemistry laboratories of public colleges in Ghana. By highlighting these concerns, the study seeks to prompt policymakers to consider revising policies to address the identified gaps.

The study's findings are anticipated to be beneficial to school administrators, teachers, and students. By addressing safety issues, educational leaders can make improvements that enhance laboratory safety, thus improving educational outcomes by creating a more conducive learning environment.

Moreover, the study is expected to support educators by enabling them to create safer teaching environments, allowing them to focus on teaching without distractions. Additionally, the research results will contribute to the existing body of knowledge on chemistry lab safety, potentially stimulating further research in this area.

1.5. Purpose of the Study

This study aims to evaluate the availability and effectiveness of safety equipment

and protocols in chemistry laboratories at Colleges of Education in Ghana. The research seeks to assess compliance with national and international safety standards by examining the current laboratory safety measures. Additionally, it aims to identify any deficiencies or gaps in these safety measures, highlighting areas for improvement. The study also evaluates the impact of laboratory safety on educational outcomes, particularly focusing on the quality of science education and practical learning experiences. Ultimately, this research will provide recommendations to enhance safety protocols and equipment, aligning laboratory practices with curriculum requirements and promoting a safer learning environment.

2. Literature Review

Chemistry laboratory safety is a critical component of educational institutions, especially within colleges of education, where future educators are trained in both theoretical and practical aspects of chemical sciences. These laboratories play a fundamental role in fostering experiential learning, allowing students to engage in hands-on experimentation and acquire a deeper understanding of chemical concepts. However, ensuring a safe laboratory environment is paramount, not only for the protection of students and faculty but also for maintaining environmental integrity. The safety protocols implemented in these institutions are vital in mitigating risks associated with hazardous chemicals and laboratory equipment. Despite their importance, there are often gaps in the execution of safety measures, particularly in terms of proper training, availability of safety equipment, and adherence to safety protocols, which can pose significant risks if not adequately addressed (Hussein & Shifera, 2022: pp. 3096-3103). This review aims to evaluate the existing literature, policy frameworks, and empirical studies on laboratory safety in educational institutions, identifying strengths, weaknesses, and potential areas for improvement to ensure a safer learning environment.

Furthermore, the physical infrastructure within educational institutions, including laboratories, plays a pivotal role in ensuring the safety and effectiveness of the learning environment. Laboratory safety is not solely dependent on the behavior and practices of the users but also on the design, layout, and maintenance of the facility itself. Essential components of a safe laboratory include proper chemical storage and handling, availability of personal protective equipment (PPE), effective ventilation systems, and well-organized laboratory layouts that allow for safe movement and emergency evacuation (Garcia et al., 2019: pp. 180-186; Zeng et al., 2017: pp. 199-208). Additionally, comprehensive risk assessments, segregation of hazardous materials, and regular equipment maintenance are necessary to prevent accidents and ensure a safe working environment. Advanced safety features, such as fume hoods, exhaust systems, and emergency response equipment, should be maintained and updated regularly to align with evolving safety standards (Akbar-Khanzadeh et al., 2012; Chowdhury et al., 2018: pp. 9819-9840). Addressing these challenges is imperative for creating safe laboratory spaces that not only protect individuals but also promote efficient and effective scientific inquiry.

International Standards and Guidelines for Laboratory Infrastructure Safety

International standards and guidelines are pivotal for ensuring laboratory safety:

- ISO 9001: Establishes a framework for quality management systems, contributing to effective safety management (Marsden & Shahtout, 2024: pp. 271-277).
- OSHA Laboratory Standard: Provides specific safety requirements for chemical hazards and laboratory infrastructure (Occupational Safety and Health Administration, 1990).
- CEN/TC 332: Offers guidelines for managing biological risks in laboratories (CEN, 2011).
- NIH Guidelines: Focus on safe handling and containment of hazardous biological materials (National Institutes of Health, 2019).
- ISO/IEC 17025: Defines requirements for laboratory competence, including safety and suitability of the working environment (Judge, 2023).

Summary of Literature Review

Chemistry laboratory safety is essential for educational institutions, particularly colleges of education, where experiential learning is critical for preparing future educators. Ensuring safe operations in these laboratories involves adhering to key safety protocols such as proper chemical storage, availability of personal protective equipment (PPE), and effective ventilation. Equally important is the overall physical infrastructure, which includes classrooms, laboratories, and other facilities that should be designed to enhance safety and learning. Safety considerations such as emergency preparedness, security measures, and regular equipment maintenance play a vital role in protecting students, faculty, and staff. International standards like OSHA's Laboratory Standard, ISO 9001, and ISO/IEC 17025 provide frameworks to ensure laboratory safety. To inform policy decisions in Ghanaian colleges of education, it is crucial to strengthen laboratory safety protocols, invest in infrastructure improvements, and align institutional policies with these global standards. Training laboratory personnel and educators on risk management and emergency preparedness is also necessary to foster a safety-conscious culture. By doing so, colleges can create a secure and conducive learning environment, reducing accidents, improving student well-being, and enhancing academic outcomes.

3. Methodology

The study is grounded in the pragmatic paradigm, which emphasizes the use of practical approaches to solve research problems. This paradigm is suitable for mixed-methods research, allowing for the integration of quantitative and qualitative data to address the research questions. Pragmatism focuses on the outcomes and implications of research rather than adhering strictly to specific methods. The study aims to evaluate the current state of safety in chemistry laboratories and gather perceptions from chemistry tutors and pre-service science teachers, aligning

with the pragmatic approach's emphasis on practical solutions.

3.1. Research Approach and Design

A mixed methods research approach was adopted, integrating both quantitative and qualitative methodologies. As emphasized by Creswell and Poth (2016), this approach offers a robust framework for addressing the research problem by capitalizing on the complementary strengths of the two paradigms.

The study employed a Concurrent Triangulation Design, also referred to as the Convergent Parallel Mixed Methods Design. This design facilitates the simultaneous collection and analysis of quantitative and qualitative data, enabling a comprehensive exploration of the safety conditions in chemistry laboratories. Quantitative data were gathered through structured questionnaires administered to chemistry tutors, as well as through direct observations of laboratory practices. Conversely, qualitative data were obtained through semi-structured interviews conducted with pre-service science teachers, providing in-depth insights into their perspectives and experiences.

3.2. Research Population and Sample Size

The study's focus group participants and questionnaire respondents were selected based on specific criteria to ensure representativeness and alignment with the research objectives. The research population comprised two primary groups: chemistry tutors and pre-service science teachers studying elective chemistry at public colleges of education in Ghana. These individuals were drawn from 18 public science colleges of education, all of which had chemistry laboratories where elective chemistry practical sessions were conducted.

For the quantitative component, questionnaires were administered to all 32 chemistry tutors in the 16 randomly selected colleges. This ensured comprehensive coverage of tutors directly involved in teaching chemistry, providing insights into laboratory infrastructure and safety protocols from an instructional perspective.

For the qualitative component, purposive sampling was employed to select pre-service science teachers for focus group interviews. From each of the 16 colleges, 10 pre-service science teachers were chosen based on their active participation in chemistry practical sessions and familiarity with laboratory practices, resulting in a total of 160 participants. To ensure fair representation of both genders and enhance the validity of findings, a stratified sampling method was employed during the selection process. This approach captured diverse perspectives on laboratory safety and infrastructure, enriching the data with nuanced, experience-based insights.

Overall, the combination of purposive and stratified sampling for focus group participants, alongside a census approach for chemistry tutors, provided a balanced and representative sample, facilitating a robust analysis of the research problem.

Area of the Study

The research was conducted across 16 Public Science Colleges of Education in Ghana.

3.3. Research Instrument

The study employed three primary research instruments: questionnaires, an observation guide, and an interview guide, all of which were adapted to suit the study's objectives. The questionnaire was adapted from [Kandel et al. \(2017: pp. 677-688\)](#) and tailored to focus on critical themes, including the state of physical infrastructure, availability of safety equipment, and awareness of safety protocols among pre-service science teachers. Specific adjustments included refining the items to address local contextual realities and emphasizing the condition of physical infrastructure. The finalized questionnaire comprised eight items and was administered to all chemistry tutors in the selected colleges. Responses were measured using a three-point Likert scale, facilitating statistical analyses such as mean and standard deviation calculations.

The observation guide, adapted for contextual relevance, consisted of seven closed-ended items designed to gather quantitative data directly from the chemistry laboratories. It assessed key parameters such as laboratory design, the status of safety equipment, and the implementation of safety protocols. Responses were categorized using a three-point Likert scale (No, Yes, N/A), ensuring clarity and consistency in data collection. Additionally, a semi-structured interview guide was developed to engage focus groups of ten pre-service science teachers from each selected college. These interviews were designed to delve into participants' perceptions, experiences, and recommendations regarding laboratory safety. The interview protocol was modified to elicit in-depth, context-specific insights, ensuring that the qualitative data complemented the findings from the questionnaire and observation guide.

3.4. Validity and Reliability

The validity of the research instruments was ensured through content and face validity processes. Content validity was achieved by adapting instruments from [Kandel et al. \(2017: pp. 677-688\)](#) to the context of Ghanaian public colleges' chemistry laboratories. Expert reviews were conducted to evaluate the relevance, clarity, and alignment of the instruments with the study objectives. Face validity was confirmed through pilot testing with a sample of participants, ensuring the items were clear and relevant. Reliability was assessed through a pilot study in a similar educational setting. The questionnaire's internal consistency was confirmed with a Cronbach's alpha of 0.82, indicating high reliability. The observation guide underwent inter-rater reliability testing, with a Cohen's kappa of 0.79, showing substantial agreement between raters. The interview guide's reliability was ensured through repeated trials, with consistent themes emerging. Triangulation of data from the questionnaire, observation guide, and interviews further enhanced the reliability, providing a well-rounded understanding of laboratory safety conditions.

3.5. Pilot Test

The research instruments for this study were pilot-tested at two colleges that share demographic similarities with the other public science colleges of education in Ghana. These colleges offer the same 4-year B.Ed program and include courses in Chemistry. The pilot test involved administering a questionnaire to all chemistry tutors (6) at these institutions and conducting semi-structured focus group interviews with ten participants in each college. The researcher also personally administered an observation guide.

The pilot testing served multiple purposes: it validated the research instruments, identified items needing revision, and refined question formats and scales. This process enhanced the instruments' validity and reliability, ensuring clear instructions, questions, and scales. By conducting a pilot test, the researcher aimed to improve the quality of data, results, and interpretations.

3.6. Data Collection Procedure

The data collection process for this study was conducted in three distinct phases to ensure systematic and reliable gathering of information. The initial phase involved obtaining research permits from the Department of Teacher Education and the Graduate School of Kwame Nkrumah University of Science and Technology (KNUST). This was followed by familiarization visits to the selected colleges, during which the researcher introduced himself, outlined the study's objectives, and engaged with key stakeholders, including college principals, heads of science departments, and chemistry tutors, to establish rapport and organize the logistics for data collection. These preparatory steps facilitated a smooth and well-coordinated data collection process.

The data collection phase itself involved the application of three key instruments: questionnaires, an observation guide, and an interview guide. Quantitative data were gathered by distributing questionnaires to all 32 chemistry tutors in the 16 randomly selected colleges. These questionnaires focused on assessing the state of physical infrastructure, safety equipment, and safety awareness. Concurrently, the researcher personally administered the observation guide to collect direct data from the chemistry laboratories, examining aspects such as laboratory design and safety protocol adherence. For qualitative data, semi-structured focus group interviews were conducted with ten pre-service science teachers from each college, selected through purposive and stratified random sampling to ensure gender representation. Participants were thoroughly briefed on the study's objectives and assured of anonymity to foster openness and accuracy in their responses. This integrated approach, combining quantitative and qualitative methods, provided a comprehensive understanding of chemistry laboratory safety in public colleges of education.

3.7. Data Analysis Procedure

The study generated both quantitative and qualitative data. Quantitative data from the questionnaires and observation guides were analyzed using the Statistical

Package for Social Sciences (SPSS) Version 27.0, focusing on descriptive statistics. Qualitative data from focus group interviews were analyzed systematically, including transcription, familiarization, coding, categorization, interpretation, and triangulation. Triangulation ensured the consistency and validity of the findings by comparing qualitative data with quantitative results.

Ethical Considerations

The study adhered to ethical standards set by KNUST, including obtaining approval from the Committee on Human Research Publications and Ethics (CHRPE). Participants provided informed consent and were assured of their right to withdraw at any time. Anonymity and confidentiality were maintained throughout, and all data collection instruments were rigorously validated to prevent bias and offensive language. The research respected the integrity of research sites and adhered to all relevant guidelines. Proper acknowledgments and references were made for all sourced materials.

4. Results and Discussion

Context and Participants:

The study involved selecting sixteen public science colleges of education at random, from which thirty-two chemistry tutors were purposefully chosen. Additionally, one hundred sixty pre-service science teachers, ten from each college, were selected to participate in focus groups. Data was also collected through direct observation by the researcher.

4.1. Quantitative Analysis

The quantitative analysis focuses on mean scores to assess participants' evaluations of various safety features. Scores near 3 suggest strong agreement with the implementation of safety measures, while scores closer to 1 indicate deficiencies. Standard deviation values are used to measure response variability, with higher deviations reflecting inconsistencies in safety features across different laboratories.

Research Question 1: Safety Status of Physical Infrastructure of Chemistry Laboratories

The data in **Table 1** and **Table 2** below describe the safety status of the physical infrastructure of chemistry laboratories. While **Table 1** presents the frequencies and the percentages of the data collected, **Table 2** depicts the average (mean) and standard deviation (Std. Deviation) for each of the items related to the safety status of physical infrastructure.

Table 1 and **Table 2** outline the safety status of chemistry laboratories in Ghanaian public science colleges, with **Table 1** showing frequencies and percentages and **Table 2** presenting mean and standard deviation for safety-related items.

The assessment of safety features in chemistry laboratories at Ghanaian Colleges of Education reveals several critical gaps and areas for improvement. The analysis of mean scores for key safety features, such as sprinkler systems and fire/smoke alarms, shows concerning deficiencies, with scores of 1.50 and 1.53, respectively.

These low scores indicate significant issues with fire safety infrastructure. The literature underscores the importance of well-designed safety measures, including adequate lighting, access control systems, and comprehensive fire safety equipment, to enhance laboratory safety and effective learning environments (Smith, 2017: pp. 16-20; Doyle, 2020: pp. 1-10; U.S. Department of Education, 2019).

Table 1. Safety status of the physical infrastructure of chemistry laboratories.

Item	Frequencies and Percentages			
	Disagree (%)	Undecided (%)	Agree (%)	Total (%)
There is provision for a pre-instructional preparatory area/teacher working space.	9 (28.1)	0 (0.0)	23 (71.9)	32 (100)
The stockroom has a separate ventilating system.	10 (31.3)	1 (3.1)	21 (65.6)	32 (100)
There is provision for materials such as water, heating electrical appliances in the laboratory.	22 (68.8)	4 (12.5)	6 (18.8)	32 (100)
Availability of working area for group or individual activities.	23 (71.9)	1 (3.1)	8 (25.0)	32 (100)
There are cabinets to store flammable chemicals, organic solvents, acids and bases separately.	15 (46.9)	0 (0.0)	17 (53.1)	32 (100)
An appropriate eye wash station facility is available in our laboratory.	24 (75.0)	1 (3.1)	7 (21.9)	32 (100)
There is a chimney.	19 (59.4)	0 (0.0)	13 (40.6)	32 (100)
N = 32				

Table 2. Means and standard deviations of responses for the safety status of the physical infrastructure of chemistry laboratories.

Item	Mean	Std. Dev.
There is a provision for a pre-instructional preparatory area/teacher working space.	2.44	0.914
The stockroom has a separate ventilating system.	2.34	0.937
There is provision for materials such as sprinkler systems, smoke alarm systems, and heat electrical appliances in the laboratory.	1.50	0.803
Availability of working area for group or individual activities.	1.53	0.879
There are cabinets to store flammable chemicals, organic solvents, acids and bases separately.	2.06	1.014
An appropriate eye wash station facility is available in our laboratory.	1.47	0.842
There is a chimney.	1.81	0.998
<i>Grand Mean</i>	1.88	

Further research supports the critical need for proper chemical storage practices and effective ventilation. Studies by Garcia et al. (2019: pp. 180-186) and Guo et al. (2020: pp. 28-33) highlight that appropriate chemical storage and clear labeling significantly reduce the risk of incidents. Zeng et al. (2017: pp. 199-208)

and Gan et al. (2020: pp. 411-448) emphasize that functioning ventilation systems, such as fume hoods, are essential for minimizing exposure to hazardous fumes and maintaining air quality.

The data also shows that while most laboratories scored relatively high on having separate stockrooms and ventilation systems (mean scores of 2.50 and 2.34), there is room for improvement in other areas. For example, eye wash stations (mean = 1.47) and chimneys (mean = 1.81) have low scores, indicating inadequate emergency facilities, which are crucial for responding to accidents and ensuring safety.

The overall mean score of 1.88 suggests that there are significant deficiencies in the physical infrastructure of the laboratories. The large standard deviations highlight considerable variability in safety features across different labs. The bar chart in **Figure 1** reveals that while most participants agree on the presence of separate chemical storage areas and ventilation systems, there is considerable disagreement on the availability of other critical safety features. Notably, many participants reported a lack of water sprinkler systems (22 disagree vs. 6 agree), fire/smoke alarms (23 disagree vs. 8 agree), and eye wash stations (24 disagree vs. 7 agree), which are essential for ensuring safety and effective emergency response. These responses have been illustrated in **Figure 1** below.

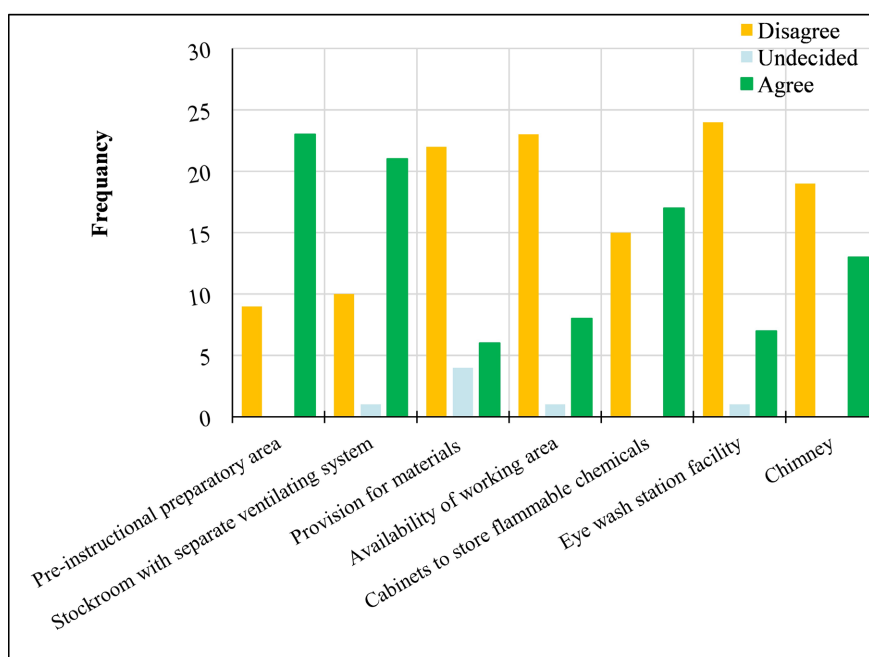


Figure 1. Frequency distribution of responses on the safety status of physical infrastructure of chemistry laboratories.

In conclusion, while some safety measures are implemented adequately, there are notable deficiencies in critical areas that require urgent attention to align with best practices and improve laboratory safety and education quality.

Observation Analysis

This study presents a detailed analysis of chemistry laboratory safety through direct observations based on 7 closed-ended items. The research assesses physical

infrastructure and safety equipment, including firefighting tools and security alarms. Observations provide immediate, authentic data, enhancing the reliability of findings compared to secondary reports. Frequency distribution bar charts categorize responses as “No,” “N/A,” or “Yes,” reflecting the presence or absence of safety features. **Table 3** and **Table 4** further discuss these observations.

Table 3. Descriptive data on the safety status of the physical infrastructure of chemistry laboratories through observation.

Item	Frequencies and Percentages			
	No (%)	N/A (%)	Yes (%)	Total (%)
Are there four outward-opening doors in the laboratory?	8 (50.0)	0 (0)	8 (50.0)	16 (100)
Are laboratory entrance doors kept closed?	6 (37.5)	0 (0)	10 (62.5)	16 (100)
Are floors dry and free of slip, trip, or fall hazards?	1 (6.3)	0 (0)	15 (93.8)	16 (100)
Are there cabinets to save flammable chemicals, organic solvents, acids, and bases separately?	8 (50.0)	0 (0)	8 (50.0)	16 (100)
A separate stockroom is used to store chemicals.	4 (25.0)	0 (0)	12 (75.0)	16 (100)
The stockroom has fire/smoke alarm systems.	14 (87.5)	0 (0)	2 (12.5)	16 (100)
An appropriate eye wash station facility is available in our laboratory.	13 (81.3)	0 (0)	3 (18.8)	16 (100)

Table 4. Means and standard deviations of responses for the safety status of the physical infrastructure of chemistry laboratories through observation.

Item	Mean	Std. Dev.
Are there four outward-opening doors in the laboratory?	2.00	1.033
Are laboratory entrance doors kept closed?	2.25	1.000
Are floors dry and free of slip, trip, or fall hazards?	2.88	0.500
Are there cabinets to save flammable chemicals, organic solvents, acids, and bases separately?	2.00	1.033
A separate stockroom is used to store chemicals.	2.50	0.894
The stockroom has fire/smoke alarm systems.	1.25	0.683
An appropriate eye wash station facility is available in our laboratory.	1.38	0.806

The analysis of the safety status of chemistry laboratories highlights crucial aspects of physical infrastructure that impact safety practices. Key findings include the status of door accessibility, floor safety, chemical storage practices, and the availability of safety equipment. Half of the laboratories meet the recommended standard of having four outward-opening doors, a vital feature for effective emergency evacuation. However, the remaining 50% lack this essential safety feature, potentially compromising emergency preparedness. Additionally, 62.5% of the laboratories keep entrance doors closed, mitigating the risk of chemical exposure, though the 37.5% that do not adopt this practice could face heightened risks. Moreover, the data on floor safety is encouraging, with 93.8% of laboratories maintaining dry, hazard-free floors, showcasing an effective approach to preventing slip, trip, or fall accidents. However, 6.3% of unsafe floors require immediate rectification

to ensure the safety of all users. The data also indicates significant gaps in chemical storage and safety systems. Only 50% of laboratories have separate cabinets for flammable and hazardous chemicals, posing a substantial risk of chemical mishaps. Additionally, 25% of the laboratories store chemicals within the main laboratory, heightening the risk of exposure. More concerning is the lack of fire or smoke alarms in 87.5% of stockrooms, a critical safety deficiency that leaves labs vulnerable to unchecked fires. Furthermore, 81.3% of laboratories lack eye wash stations, an essential facility for emergency first aid in case of chemical exposure. These deficiencies highlight the urgent need for better safety protocols. The findings underscore the importance of enhancing safety equipment, such as fire alarms and eye wash stations, improving chemical storage practices, and ensuring emergency preparedness measures like outward-opening doors are implemented consistently across all laboratories. Addressing these issues will promote safer laboratory environments and align practices with safety standards. (Figure 2)

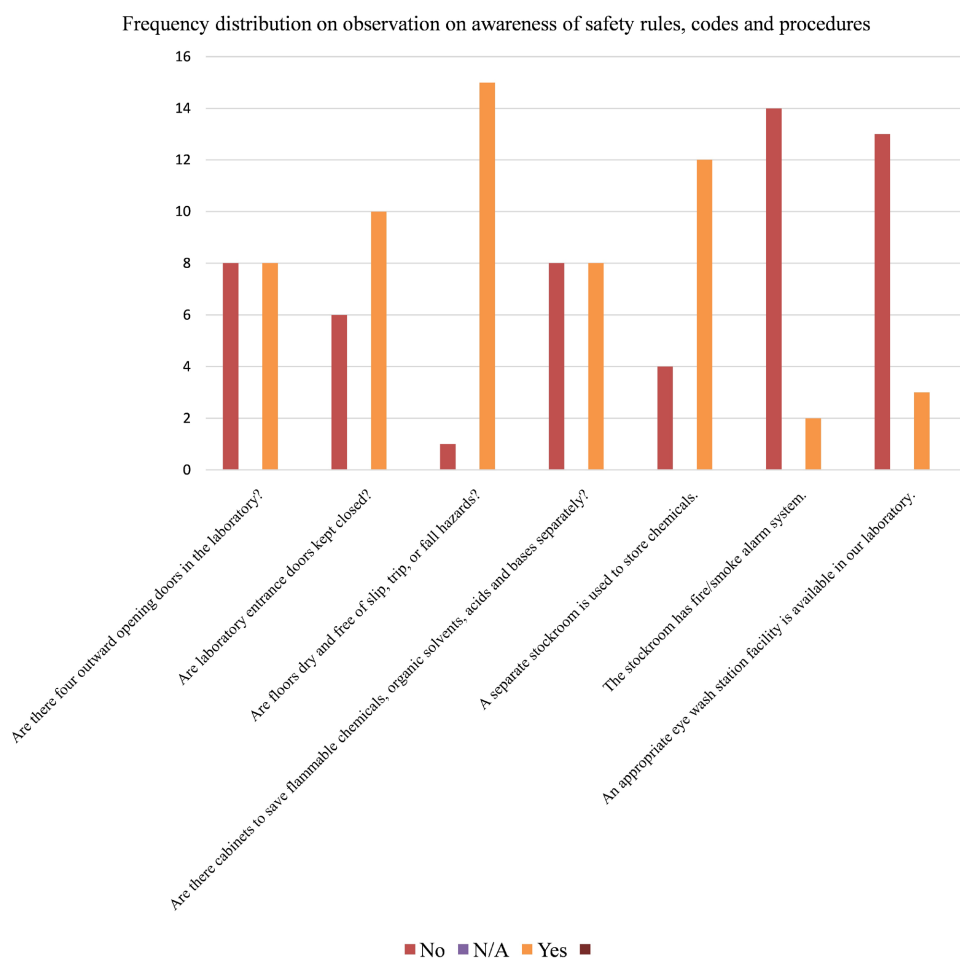


Figure 2. Frequency distribution on observation on the safety status of the physical infrastructure of chemistry laboratories.

4.2. Qualitative Analysis

The physical infrastructure of chemistry laboratories at Ghanaian colleges of

education faces significant safety issues. Qualitative analysis from focus group interviews with 160 pre-service science teachers reveals concerns such as inadequate space, poor design, outdated equipment, and insufficient safety protocols. Key issues include the lack of proper chemical storage, emergency exits, and ventilation systems. Safety protocols are poorly enforced, and there is infrequent inspection and maintenance. To enhance safety, improvements are needed in storage practices, facility renovations, and safety policy enforcement.

4.3. Physical Infrastructure and Design

The theme of Physical Infrastructure and Design is crucial, underscoring a significant gap between the ideal standards and the existing conditions. Interviews from the focus groups reveal a varied perception among students regarding the adequacy of their laboratory's physical infrastructure.

Participants expressed mixed views on the laboratory's standards, with some indicating adequacy while others noted the absence of practical sessions.

“From my experience, I think they are quiet up to standard.” contrasts with “Please, since we’ve not started out practicals yet, we’ve not started using the chemicals and then the apparatus at the lab, so I can’t really say it is up to standard. We’ve seen some of the apparatus and some of the chemicals, but we’ve not started practicals as I said, so, we don’t know what we are going to use, what is there and what is not there.”

This reflects Smith and Johnson's (2021: pp. 43-57) assertion that “the adequacy of laboratory infrastructure critically influences the effectiveness of safety education and practical learning experiences. This participant was of the view that giving a verdict on the standard of the lab design would be difficult since they haven't had hands-on practice at the lab yet.

The interviews highlight that while some students perceive their laboratories to be up to standard, others express concerns due to the lack of practical experience and insufficient use of equipment and chemicals.

One participant stated, *“It's well designed with benches and tables and appropriate tools, but...we are actually more than the people expected to work within the lab.”*

Another participant also stated, *“From my experience, I think they are quiet up to standard. Since they meet the requirements, I will say they are up to standard.”*

The findings on physical infrastructure and design in this study highlight a critical disparity between ideal standards and actual conditions, particularly in the context of laboratory environments at educational institutions. Best practices in laboratory design emphasize both physical adequacy and active use of the infrastructure to support effective learning. However, the mixed perceptions from students suggest that while some facilities may meet minimum physical standards, the lack of practical engagement with laboratory equipment and chemicals may limit their effectiveness in delivering a comprehensive educational experience.

Several students acknowledged that their laboratories were well-equipped,

featuring appropriate tools, benches, and tables.

Yet, concerns were raised regarding overcrowding and limited practical sessions, reflecting that physical adequacy alone does not equate to functional adequacy. This is in line with Smith and Johnson's (2021: pp. 43-57) argument that "the adequacy of laboratory infrastructure critically influences the effectiveness of safety education and practical learning experiences." Without the opportunity to engage in hands-on activities, students are unable to fully assess or benefit from the available resources. As such, the absence of practical sessions detracts from the overall educational experience and the intended purpose of the laboratory infrastructure.

In terms of best practices, this finding implies that physical design must be coupled with regular, structured practical sessions to realize the full potential of laboratory environments.

Laboratories that meet basic physical standards but lack sufficient opportunities for students to interact with equipment may fall short of educational objectives, as supported by research showing that hands-on learning enhances both comprehension and retention of scientific concepts (Brown et al., 2020: pp. 245-259). Additionally, the issue of overcrowding must be addressed, as it can impede the effectiveness of both safety measures and practical instruction, aligning with the standards proposed by the International Science Teaching Association (ISTA, 2019) cited in Cianca (2019).

In summary, the study suggests that best practices in laboratory design should extend beyond mere physical adequacy to include provisions for frequent and meaningful practical experiences while also ensuring that laboratory capacity aligns with the student population. The findings reinforce the need for educational institutions to regularly assess not only the physical infrastructure of their laboratories but also the functional use of these spaces to ensure they are meeting both educational and safety standards.

4.4. Incidents and Responses

The theme of Incidents and Responses in Ghanaian Colleges of Education chemistry labs reveals a gap in formal incident reporting and response protocols. Focus group discussions highlight varied accident experiences and a lack of preparedness. Scholars recommend a holistic approach, emphasizing ongoing safety training, PPE provision, and structured incident management strategies to improve lab safety.

A participant from FG6 shared,

"We kind of just follow what the tutor says, but there's no formal list of rules we're shown,"

This, while discussing safety rules, indirectly points to a lack of structured response strategies for when incidents occur.

Furthermore, some participants recount a particularly alarming incident from a student's previous experience,

“That was when I was in SHS. A certain student added water to an acid in that caused an explosion and then the person was rushed quickly to the hospital. That was my experience.”

“Way back SHS, we were doing titration. One of the pipette glasses got broken and it nearly cut the student who was using the pipette to do the titration.”

This narrative not only highlights the risks inherent in chemistry labs but also the critical need for effective response strategies to mitigate these risks.

The group shared experiences with minor accidents and near misses, underscoring the need for better accident preparedness and response strategies.

“A friend of mine mishandled the apparatus...it splashed out.”

“Yeah, we were doing practical on titration. And I pipette some of the chemicals into, inside me. And I get burn within my heart.”

“One guy ended up drinking the base while using the pipette.”

This emphasizes the need for clear incident response protocols and a culture where accidents are promptly addressed, as recommended by [Thompson \(2023\)](#). While no accidents were reported, this may indicate underreporting or a lack of significant incidents. [Taylor \(2021: pp. 249-263\)](#) stresses the importance of open dialogue and safety training to manage risks effectively. The discussion revealed unpreparedness, as participants lacked orientation and clear reporting mechanisms. [Thompson \(2023\)](#) also highlights the importance of communication channels for effective incident response. Some participants were aware of incident reporting procedures, but overall preparedness remains inadequate for potential hazards.

“Okay. So, in the case of an accident in the laboratory, the first point of contact is whoever is in charge of the laboratory at the moment for which the incident occurred. So, we report to the person in charge, either the lab assistants or the tutor present. So, we report the teacher. And then afterwards, we rush to the emergency meeting points. That is the quadrangle, as my sister said. That's the actions we take.”

“During our orientation, we were being given an information with regard to how information's are being channeled to the various authorities. So, with regard to laboratory equipment and accidents and other stuff, I think that one we can have a first aid before we take the next process or the next process is being taken.”

“And I also suggest, even though we've not being told where to channel our grievances to, but I think we can see the tutor who is in charge so as to their rights decisions to take.”

“In case there is an accident, the chemistry lecturer would be the person that would attend to the victim”

It turned out that most were not aware of the reporting protocols.

“Sir, we don't know because our tutors haven't communicated that to us. If there is an emergency or any challenge, the person we should report to.”

“Since we said we've never been taken through an orientation as to how we should comport ourselves when there are hazards. So, it is difficult for us to know

the person and if we experience any risk of injury, you can report to the person.”

Discussions on Incidents and Responses in Ghanaian colleges of education’s chemistry labs highlight the need for stronger preventive measures and emergency response protocols. Integrating student experiences with scholarly insights emphasizes the importance of a proactive safety culture. Institutions should implement structured response protocols, regular safety orientations, and ongoing training. This ensures students not only prevent accidents but are also prepared to respond effectively. Such measures foster a resilient safety culture, equipping students with the knowledge and skills to manage incidents in line with best practices advocated by experts.

Inspection and Maintenance

The theme of Inspection and Maintenance is integral to ensuring a safe laboratory environment. Discussions from various colleges of education in Ghana reveal a troubling absence of regular inspection and maintenance schedules for laboratory equipment and safety features. This neglect not only endangers students’ safety and well-being but also undermines the integrity of educational outcomes. Students’ firsthand accounts of the infrequent or non-existent routine inspections and maintenance practices highlight a significant discrepancy between recommended safety protocols and actual practices within these educational laboratories. Expert recommendations underscore the necessity for regular inspections and thorough maintenance, emphasizing the need for institutions to prioritize laboratory upkeep to safeguard students and enhance the educational experience.

Participants’ observations suggest a pervasive lack of routine inspections, with specific issues such as non-functional sinks and inadequate ventilation reported. For instance, the condition of benches and stools, described as “loose and shaking,” illustrates pressing maintenance concerns. Clark (2021) underscores the critical role of routine inspections in identifying and addressing potential safety hazards promptly.

A participant’s comment from FG6, “Sir, once... That was once,” regarding the frequency of safety inspections, starkly highlights the infrequent oversight crucial for upholding laboratory safety standards. Similarly, FG12 participants lamented, “We’ve never seen that before,” in response to questions about equipment maintenance and safety checks, illustrating a systemic issue where routine safety protocols are severely neglected.

The discussions reveal an absence of regular inspections by authorities or college staff, with one participant noting, “I’ve not seen any agency, not even one.” This lack of oversight is critiqued by Hanson et al. (2011: pp. 127-142), who asserts, “Regular safety inspections are essential in identifying and mitigating risks, ensuring a safe and compliant laboratory environment.”

Neglected maintenance and inadequate inspection regimes contribute significantly to infrastructure-related accidents. Failure to address issues such as corrosion, wear and tear, or structural weaknesses can lead to unforeseen failures (Gransberg et al., 2015: pp. 343-361). Routine maintenance, periodic inspections, and

condition assessments are essential for detecting potential risks and ensuring timely repairs or replacements. Walters & Spencer (2021: pp. 105-112) emphasize the need for rigorous safety oversight, while Lee advocates for the inclusion of orientation and ongoing safety training, including equipment use and maintenance protocols.

Maintaining physical infrastructure safety in chemistry labs is vital to ensure the well-being of laboratory personnel, prevent accidents, and properly handle hazardous materials. Challenges in maintenance and equipment malfunctions pose significant risks, with neglected schedules and faulty equipment increasing the likelihood of accidents (Rajput et al., 2018: pp. 1-14). Regular maintenance and timely repairs are crucial for the safe operation of laboratory infrastructure.

The discussions about Inspection and Maintenance within Ghanaian colleges of education's chemistry laboratories highlight a critical need for improvement. Integrating students' firsthand experiences with scholarly recommendations reveals that a structured approach to inspections and maintenance is not only advisable but essential. Educational institutions must establish and adhere to regular inspection schedules and maintenance routines as part of a broader commitment to laboratory safety. This commitment should extend beyond mere compliance to embrace a culture of continuous improvement and safety excellence. By prioritizing these improvements, colleges can ensure that laboratory facilities remain safe, functional, and conducive to high-quality education.

4.5. Suggestions for Improvement

Focus group discussions reveal several areas requiring immediate attention and improvement in chemistry laboratories. Suggestions encompass enhancing physical infrastructure, ensuring the availability of safety equipment, and formalizing safety education and training.

A participant from FG10 emphasized the need for proper orientation, stating, "There must be a proper orientation so that we will know what we have to take in the course as chemistry students." This highlights a significant gap in initial laboratory safety training for students. Concerns about insufficient safety equipment are echoed in FG7, where a participant noted, "No sir... If there is, we haven't seen it yet," pointing to the absence of essential personal protective equipment (PPE).

Recommendations for improvement include updating equipment and ensuring the availability of PPE. Participants suggested, "Some of the equipment needs to be changed, for example, ventilation." Another participant advocated for integrating technology, noting, "With advancements in technology, simulations can enhance safety and learning, but physical equipment needs regular updates." Duncan (2022: pp. 497-511) supports this by advocating for technological integration in science education to improve safety and learning outcomes.

Additional suggestions included labeling chemicals for proper use and increasing emergency exits. A participant proposed, "Most chemicals should be labeled

for proper use, and emergency exits should be ample to facilitate safe evacuation in case of an accident.” Training on equipment use was also recommended: “Researchers and students need training on how to use laboratory apparatus.”

Participants also proposed increasing laboratory space to reduce overcrowding: “Increasing the lab area can decrease hazards by allowing more space for maneuverability.” This reflects a push towards modernizing laboratory practices and enhancing safety. Mitchell (2024) supports the use of technology, such as virtual labs, to offer safer and more accessible learning experiences.

These recommendations align with Davis and Johnson’s advice on improving laboratory safety through infrastructure investment, clear safety communication, and policy implementation. Enhanced safety measures contribute to risk mitigation and cost reduction. Robust safety protocols help prevent accidents, minimize injuries, and mitigate liability, thereby protecting valuable equipment and resources. Proactive safety measures lead to long-term cost savings for educational institutions (Cox & Roffey, 2017: pp. 23-31; Gray et al., 2021: pp. 303.e1-303.e17).

Integrating student feedback with scholarly recommendations offers a clear pathway for enhancing laboratory safety. This synthesis not only validates student concerns but also provides a research-backed framework for addressing these issues. The collective insights from focus groups, reinforced by literature, highlight the need for structured safety orientations, adequate PPE, and continuous safety training. Institutions must adopt a proactive stance on regular inspections and maintenance to uphold safety standards. Prioritizing these improvements will significantly enhance the safety, efficacy, and quality of the learning experience in chemistry laboratories.

4.6. Discussion

The assessment of safety standards in chemistry laboratories at Ghanaian public colleges of education reveals significant deficiencies in infrastructure, safety mechanisms, and emergency preparedness. Quantitative data indicate substandard provisions for critical safety features, such as sprinkler systems (mean score: 1.50) and fire alarms (mean score: 1.53), underscoring the inadequacy of fire safety measures. Although marginally better scores were observed for separate chemical storage (2.50) and ventilation systems (2.34), essential facilities like eye wash stations (1.47) and chimneys (1.81) remain insufficiently provided. Observational findings reveal only 50% of laboratories meet evacuation standards, 62.5% maintain closed entrance doors to limit chemical exposure, and 93.8% ensure dry, hazard-free floors. However, poor chemical storage and the absence of fire alarms in 87.5% of stockrooms exacerbate safety risks, necessitating urgent improvements in laboratory infrastructure and protocols (Smith, 2017: pp. 16-20; U.S. Department of Education, 2019). Qualitative evidence from focus group discussions corroborates these quantitative findings, highlighting issues such as overcrowding, outdated equipment, insufficient practical engagement, and poor enforcement of safety standards. Participants noted the absence of structured safety orientations

and inconsistent communication of emergency procedures, leaving students unprepared to respond to laboratory hazards. Accounts of malfunctioning equipment, poor ventilation, and neglected maintenance reflect systemic issues, with studies by Walters and Spencer (2021: pp. 105-112) and Gransberg et al. (2015: pp. 343-361) emphasizing the role of regular inspections and upkeep in mitigating risks. These findings underscore the critical need for an integrated approach to safety management, including routine maintenance, functional safety systems, structured safety training, and effective communication protocols. Such measures, aligned with the recommendations of Thompson (2023) and ISTA (2019), are imperative to transforming laboratories into secure and conducive environments for teaching and learning.

4.7. Summary

The study revealed substantial deficiencies in key safety features within chemistry laboratories in public Colleges of Education in Ghana. The absence of essential fire safety equipment and insufficient emergency response infrastructure were major concerns. Qualitative data from pre-service teachers corroborated these findings, highlighting additional challenges such as outdated equipment, overcrowded labs, and a lack of safety protocols. Insufficient orientation and training exacerbated these risks, as many students were unaware of whom to contact in the event of an accident. Furthermore, the lack of regular inspections and routine maintenance underscored systemic safety gaps, with deteriorating laboratory conditions and equipment often reported by students.

4.8. Conclusion

Inadequate safety measures in Ghanaian Colleges of Education chemistry laboratories jeopardize the safety of students and undermine educational quality. Critical infrastructure deficiencies, such as the lack of fire/smoke alarms, malfunctioning equipment, and poor ventilation systems, combined with inadequate emergency preparedness, create a hazardous environment for laboratory users. The absence of proper orientation and routine maintenance further compounds these issues, leaving students ill-prepared to manage potential accidents. This study underscores the urgent need for a proactive safety culture in laboratories, aligning with international best practices in laboratory safety.

4.9. Recommendations

To address the identified deficiencies and improve safety standards in chemistry laboratories, the following recommendations are proposed:

- 1) Strengthen Fire and Emergency Preparedness: Colleges should install and maintain fire safety systems, including fire alarms, sprinklers, and clearly marked emergency exits, to ensure quick responses in the event of an accident.
- 2) Regular Inspections and Maintenance: Institutions must implement strict inspection schedules to ensure that laboratory equipment is functional, and the

infrastructure is well-maintained. Routine maintenance should address equipment malfunctions, ventilation issues, and structural weaknesses in laboratory furniture.

3) Safety Training and Orientation: Colleges should provide comprehensive safety training and orientation sessions for all laboratory users, focusing on emergency protocols, the use of personal protective equipment (PPE), and the proper handling of chemicals.

4) Update Laboratory Infrastructure: Outdated equipment should be replaced, and laboratory spaces should be expanded to reduce overcrowding, which poses significant safety risks. Integrating new technologies, such as simulations and virtual labs, can complement physical equipment and enhance both learning and safety outcomes.

5) Enhance Communication Channels: Clear reporting protocols and communication channels should be established for students to report accidents or hazards. This includes designating safety officers and ensuring that students are familiar with emergency response procedures.

By implementing these measures, Ghanaian Colleges of Education can create a safer, more conducive learning environment that aligns with global best practices and protects both students and laboratory personnel from potential hazards.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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