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Evaluation of Chemical Health and Safety Practices and Exposure Risks in Undergraduate Chemistry Laboratory Practicum

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ABSTRACT

Purpose of the study: This study aims to evaluate the implementation of chemical health and safety practices in undergraduate chemistry laboratory practicum by focusing on chemical hazard identification and exposure risk assessment associated with laboratory activities involving hazardous substances.

Methodology: The research employed a descriptive observational design using a structured chemical safety checklist and a task-based risk assessment approach. The evaluation considered chemical properties such as toxicity, flammability, and corrosivity, as well as potential exposure pathways including inhalation, dermal contact, and accidental ingestion. Laboratory activities were analyzed based on the likelihood of exposure and the severity of potential health impacts to determine risk levels.

Main Findings: The results indicate that, although overall safety practices were categorized as acceptable, several laboratory activities involving hazardous chemicals such as nitric acid, sulfuric acid, and benzene present significant chemical exposure risks. High-risk conditions were mainly associated with improper handling of corrosive and flammable substances and inconsistent use of personal protective equipment. These conditions suggest the presence of both acute exposure risks, including chemical burns and irritation, and potential chronic health risks due to repeated low-level exposure in laboratory environments.

Novelty/Originality of this study: This study contributes to chemical health risk prevention by integrating chemical hazard characteristics and exposure pathways into a task-based risk assessment framework in an academic laboratory setting. Unlike previous studies that primarily focus on general safety practices, this research emphasizes exposure-based chemical health risk evaluation, providing a more comprehensive approach to improving chemical safety management in chemistry laboratory education.

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1. INTRODUCTION

Practical laboratory activities play an essential role in chemistry education because they allow students to experience scientific concepts through direct experimentation [1]-[3]. In chemistry learning, laboratory work supports the development of scientific reasoning, technical skills, and problem-solving abilities [4], [5]. However, laboratory activities also involve potential hazards due to the use of chemicals, glassware, and various experimental equipment [6], [7]. These potential risks highlight the importance of implementing appropriate safety procedures during laboratory practice. Therefore, chemical health and safety principles must be integrated into chemistry laboratory learning to ensure safe and effective experimental activities [8], [9].

The implementation of laboratory safety is a critical component in maintaining a safe learning environment for students and instructors [10], [11]. Laboratory safety practices include the use of personal protective equipment, proper chemical handling, safe laboratory behavior, and adherence to established safety protocols [12], [13]. In many higher education institutions, safety training is provided to students before they participate in laboratory work [14], [15]. Such preparation is intended to minimize accidents and ensure that students understand the potential hazards associated with chemical experiments. Consequently, students are expected to apply safety procedures consistently during laboratory activities.

Pre-service chemistry teachers are expected to possess not only strong conceptual knowledge of chemistry but also the competence to manage laboratory activities safely [16], [17]. As future educators, they will be responsible for supervising laboratory experiments and ensuring that safety standards are followed in school laboratories. Therefore, the ability to implement laboratory safety procedures is an essential competency that should be developed during their university education [18], [19]. Practical courses in chemistry provide an important opportunity for students to learn and practice safety behaviors [20], [21]. Developing this competence is particularly important to promote a culture of safety in chemistry education.

In recent years, laboratory safety has received increasing attention in science education research worldwide. Universities in several countries have emphasized the integration of safety culture and risk awareness into laboratory teaching practices [22], [23]. Studies have highlighted that students' safety behavior is influenced not only by their knowledge but also by their attitudes and practical skills during laboratory activities [24], [25]. Despite these efforts, gaps still exist between safety knowledge and actual safety practices among students. This indicates that evaluating students' ability to apply safety procedures during laboratory work remains an important area of investigation [14], [26].

Although many studies have discussed laboratory safety awareness and safety knowledge among students, fewer studies have specifically examined how well students apply chemical health and safety principles during chemistry laboratory practicum [21], [27]. Most existing studies focus on theoretical understanding or perception of safety rather than practical implementation in real laboratory settings [2], [28]. As a result, the extent to which pre-service chemistry teachers are able to translate safety knowledge into actual laboratory practice is still not fully understood [29], [30]. Understanding this aspect is crucial for improving safety training in chemistry education programs. Therefore, further research is needed to analyze students' practical ability to apply laboratory safety procedures.

This study offers a perspective that focuses specifically on the analysis of students' ability to implement chemical health and safety principles during chemistry laboratory activities [31], [32]. By examining the practical behavior of students in applying safety procedures, this research provides a more comprehensive understanding of laboratory safety competence among pre-service chemistry teachers [33], [34]. The findings are expected to contribute to improving laboratory safety education and strengthening safety culture in chemistry learning environments [35], [36]. In addition, the study may provide useful insights for designing more effective safety training programs in higher education institutions. Such improvements are essential to ensure that future chemistry teachers are adequately prepared to manage safe laboratory environments.

Considering the importance of laboratory safety in chemistry education and the limited research focusing on the practical application of safety procedures, it is necessary to examine how well pre-service chemistry teachers implement chemical health and safety principles during laboratory work. Evaluating students' ability to apply safety procedures can provide valuable information for improving laboratory instruction and safety training [37], [38]. This information may also help institutions develop more effective strategies for fostering safety awareness and responsible laboratory behavior [39], [40]. Furthermore, strengthening safety competence among future teachers can contribute to safer laboratory practices in schools [41], [42]. Therefore, this study aims to analyze the ability of chemistry education students to implement chemical health and safety practices during chemistry laboratory practicum.

Chemical laboratories involve a wide range of hazardous substances, including corrosive acids, flammable organic solvents, and toxic chemical vapors [43], [44]. These substances present potential health risks through multiple exposure pathways such as inhalation, dermal contact, and accidental ingestion [45], [46]. Acute exposure may result in immediate effects such as chemical burns, irritation, or respiratory distress, while chronic exposure may lead to long-term health impacts due to repeated low-level contact with hazardous chemicals [47], [48]. Despite the importance of laboratory safety practices, many studies still emphasize procedural compliance without explicitly addressing exposure-based chemical health risks. Therefore, a more comprehensive evaluation that integrates chemical hazard characteristics and exposure pathways is necessary to improve chemical health and safety management in academic laboratory environments.

In international chemical safety frameworks, laboratory safety is not only defined by procedural compliance but also by risk awareness and safety culture. Previous studies in chemical health and safety emphasize that laboratory accidents are strongly influenced by individuals' perception of risk and their ability to recognize hazardous conditions during experimental activities [49], [50]. Therefore, effective chemical health and safety management requires the integration of hazard identification, exposure assessment, and safety behavior into laboratory practices [51], [52]. This perspective highlights that safety in chemistry laboratories should be evaluated not only based on observable procedures but also on the potential risks and exposure associated with chemical handling.

2. RESEARCH METHOD

2.1. Research Methods

This study employed a descriptive research design to examine the implementation of chemical health and safety practices during chemistry laboratory practicum. A descriptive approach was used to provide a systematic description of students' ability to apply laboratory safety procedures during experimental activities [53], [54]. The study focused on identifying how pre-service chemistry teachers implement safety practices while conducting laboratory experiments. Through this approach, the research aimed to capture the existing conditions of safety implementation in the chemistry laboratory environment. The findings are expected to present an overview of students' practical ability to apply chemical health and safety principles during laboratory work [7], [26].

2.2. Research Procedures

The research procedure was conducted through several stages. The first stage was the preparation stage. This stage included conducting a literature review to identify the research problem and establish the theoretical foundation of the study [55], [56]. In addition, a needs analysis was carried out by examining the chemistry laboratory practicum modules used in undergraduate chemistry education courses. The analysis aimed to identify practicum topics that involve laboratory skills and potential chemical health and safety risks during experimental activities.

The second stage involved the development of research instruments. In this stage, the observation instrument was designed based on the results of the initial analysis of laboratory activities and safety procedures. The instrument was then evaluated and validated by experts to ensure its relevance and appropriateness for measuring students' ability to implement laboratory safety practices [34], [57]. Revisions were made according to the feedback provided by the experts. To ensure the reliability of the instrument, an agreement test among observers was conducted. Three observers simultaneously observed the activities of a laboratory practitioner, and the observation process was repeated with different participants to determine the consistency of the instrument.

The final stage was the implementation stage. Data were collected using the observation sheet during selected chemistry laboratory practicum sessions that involved experimental procedures with potential safety risks [58], [59]. Prior to the data collection process, the observers received guidance and training on how to use the observation instrument to ensure consistency in recording observations. Each observer monitored one participant during the laboratory activity. The collected data were then analyzed to address the research objectives. The results were presented in graphical and descriptive forms, followed by interpretation and formulation of conclusions based on the findings of the study.

2.3. Population and Sample

The population of this study consisted of undergraduate students enrolled in the Chemistry Education program. These students were selected because they regularly participate in laboratory practicum as part of their academic training. From this population, a group of sixth-semester students was chosen as the research sample [60], [61]. A total of 35 students participated in this study.

The sampling technique used in this research was purposive sampling. This technique allows researchers to select participants based on specific considerations relevant to the research objectives [62], [63]. The selected students had completed most of the required chemistry laboratory practicum courses during their previous semesters. Therefore, they were considered to have sufficient experience and understanding of laboratory activities as well as chemical health and safety principles. This condition made them suitable participants for evaluating the implementation of laboratory safety practices during chemistry practicum.

2.4. Data Collection Techniques

The data in this study were obtained through observations of the implementation of chemical health and safety practices during chemistry laboratory activities. The primary data source consisted of undergraduate students in the Chemistry Education program who participated in laboratory practicum sessions [64], [65]. Data collection was conducted using an observation technique to examine students' behavior and practices related to laboratory safety procedures.

An observation sheet was used as the main research instrument to record students' actions during laboratory activities [66], [67]. This instrument allowed the observers to systematically document students' compliance with safety procedures, laboratory work practices, and the use of safety equipment. The observation process was carried out directly in the chemistry laboratory during practicum sessions. The duration of each observation was adjusted according to the practicum activities performed by the participants.

The observations conducted on the research participants served as the primary dataset of the study. The collected data were then compiled and analyzed to identify patterns in the implementation of laboratory safety practices among students [68], [69]. The results of the analysis were used to draw conclusions regarding students' ability to apply chemical health and safety principles during chemistry laboratory practicum.

The observation instrument was designed to evaluate chemical health and safety practices by incorporating indicators related to chemical properties, including toxicity, flammability, and corrosivity. In addition, the assessment considered potential exposure pathways such as inhalation of chemical vapors, dermal contact with hazardous substances, and accidental ingestion during laboratory activities [70], [71].

2.5. Data Analysis Techniques

The observation sheet was used as the primary instrument to record the implementation of chemical health and safety practices during chemistry laboratory activities. The instrument was completed by observers based on their direct observation of students' safety practices during the practicum [72], [73]. Each observed behavior related to laboratory safety was marked using a checklist on the observation sheet according to the specified criteria. This approach allowed the observers to systematically document the occurrence of safety-related actions performed by the students.

The measurement scale applied in this study was a rating scale. In this model, the assessment was based on quantitative scores that represent the level of students' ability to implement laboratory safety practices [74], [75]. The rating scale enabled the researchers to evaluate various aspects of laboratory activities, including safety behavior, work procedures, and compliance with safety standards during experimental work.

The collected data were processed through several analytical steps. First, the observation sheets were completed by marking the checklist for each safety aspect observed during the practicum. Second, the scores obtained for each indicator in the observation sheet were summed to determine the total score for each participant. Third, the raw scores were converted into percentage values by comparing the obtained score with the maximum possible score. The percentage value was calculated using the following formula:

$$NP = \frac{R}{SM} x\, 100 \ldots (1)$$

where NP represents the percentage score, R is the raw score obtained by the participant, and SM is the maximum possible score.

After calculating the percentage values, the average score for each sub-indicator of laboratory safety was determined by dividing the total score obtained by the number of assessed aspects. Furthermore, the average score for each main indicator of laboratory safety was calculated by averaging the scores of all related sub-indicators. These calculations allowed the researchers to evaluate students' overall ability to implement chemical health and safety practices during laboratory activities. Finally, the percentage results obtained from the observations were interpreted using predetermined score interpretation criteria. The percentage scores were categorized into five levels of performance: very good (81–100%), good (61–80%), moderate (41–60%), poor (21–40%), and very poor (0–20%). These categories were used to describe the level of students' competence in applying chemical health and safety procedures during chemistry laboratory practicum.

The task-based risk assessment was conducted by analyzing each laboratory activity in terms of likelihood of exposure and severity of potential health impacts. The severity level was determined based on the intrinsic properties of the chemicals used, including their reactivity, toxicity, and corrosive nature [76], [77]. This approach enabled the identification and prioritization of chemical health risks rather than general safety issues.

In addition to descriptive analysis, this study adopts a risk-based chemical safety evaluation framework aligned with international chemical health and safety standards. The task-based risk assessment was conducted by integrating hazard identification, exposure likelihood, and severity of potential health impacts. Hazard identification was based on the intrinsic properties of the chemicals used in the laboratory, including toxicity, flammability, corrosivity, and reactivity [78], [79]. Exposure likelihood was evaluated based on students' behavior and compliance with safety procedures, while severity was determined based on the potential health consequences of chemical exposure. This approach enables a more comprehensive evaluation of chemical health risks by combining procedural safety assessment with exposure-based risk analysis, which is widely recommended in international chemical safety practices.

3. RESULTS AND DISCUSSION

Observations were conducted to analyze the implementation of chemical health and safety practices in the laboratory during two chemistry practicum activities, namely the synthesis of nitrobenzene and the determination of moisture and ash content in biscuits. Through the observation sheets, information was obtained regarding the ability of sixth-semester Chemistry Education students to apply laboratory safety procedures during experimental activities. The results obtained from these observations constitute the primary data of this study. Data collection was carried out by four observers who monitored the students' activities during the practicum sessions. Table 1 presents the data describing students' laboratory safety performance, including the percentage distribution of each observed skill across the two practicum topics.

Table 1. Ability to Implement Chemical Health and Safety in the Laboratory

No	Criteria	Safety and Security Aspects of Laboratory Work	% Chemical Health and Safety Laboratory	
			Average	Category
A.	Preparation	Personal protective equipment (Wearing a laboratory coat, special gloves, laboratory glasses, respirator, wearing closed shoes)	75	Good
Average			75	Good
B.	Preparation	Weighing 6 grams of solid CaCl2 and 2 grams of biscuits	75	Good
		Weighing a crucible and a porcelain cup	76	Good
		Measuring the volume of concentrated nitric acid (explosive) and concentrated sulfuric acid (corrosive) (complete PPE, special neoprene gloves, special mask (respirator), performed in a fume hood)	79	Good
		Measuring the volume of benzene (flammable) (complete PPE, special neoprene gloves, special mask (respirator), performed in a fume hood)	75	Good
		Preparing 10 ml of 10% NaOH reagent (complete PPE, special neoprene gloves, special mask (respirator)	69	Good
		Average	75	Good
C.	Core activities	Heating a porcelain crucible in an oven (complete PPE, using special heat-resistant gloves and a special mask (respirator)	77	Good
		Cooling the porcelain crucible in a desiccator	83	Very Good
		Cleaning the crucible with alcohol	82	Very Good
		Firing a crucible containing biscuits in a furnace	73	Good
		Mixing concentrated nitric acid with concentrated sulfuric acid (complete PPE, using special neoprene gloves and a special mask (respirator), performed in a fume hood)	60	Enough
		Mixing benzene into the solution (full PPE, using special neoprene gloves and a special mask (respirator), performed in a fume hood)	59	Enough
		Heating and letting the mixture stand in a water bath (full PPE, using special heat-resistant gloves and a special mask (respirator))	63	Good
		Adding water to the layer	68	Good
		Adding 10% NaOH	59	Enough
		Adding 6 grams of solid CaCl2	62	Good
		Average	69	Good
D.	Final activities	Material Storage (reagents are returned to the substance room, knowing the qualifications of each substance, and placing the substances according to their properties and handling)	88	Very good
		Equipment Storage (tools are returned to the tool room, knowing the qualifications of each tool, and placing the substances according to their weight and base material)	94	Very good
		Liquid Waste (Dilute the materials used, dispose of them in a place appropriate to the material's qualifications, and clean the used tools)	60	Enough

No	Criteria	Safety and Security Aspects of Laboratory Work	% Chemical Health and Safety Laboratory	
			Average	Category
		Solid Waste (Differentiate between recyclable and non-recyclable waste, dispose of them in a place appropriate to the material's qualifications, and clean the used tools)	55	Enough
		Average	74	Good
E.	Treatment in case of an accident	Inhalation of toxic gas (induce vomiting, give milk, coffee, or warm water, and bring to a clean area)	46	Enough
		Sprayed with chemicals (run water over the affected area, do not wipe directly with a cloth, and apply cream/lotion)	77	Good
		Fire (wet a towel and drape it over the burning flame, prepare a fire extinguisher, and keep other flammable materials away from the fire)	82	Very good
		Electric shock (turn off the power source, unplug the power cord, and do not touch the victim while being electrocuted)	74	Good
		Average	70	Good
		Total average		Good

From an international chemical safety perspective, the results indicate that safety performance alone does not fully represent actual risk conditions. Although students demonstrated generally good safety practices, several activities still present high chemical health risks due to the hazardous nature of the substances involved [80], [81]. In particular, activities involving concentrated nitric acid, sulfuric acid, and benzene represent significant risk scenarios due to their high corrosivity, toxicity, and flammability. The relatively lower scores in these activities suggest increased exposure likelihood, which, when combined with high severity, may lead to critical risk levels despite acceptable procedural performance.

The results presented in Table 1 indicate that the overall implementation of chemical health and safety practices among Chemistry Education students was categorized as good, with an average percentage score of 73%. In the preparation stage, the use of personal protective equipment showed a good level of compliance, with a percentage of 75%. Similarly, the preparation phase of the practicum activities demonstrated a good level of safety implementation, with an average score of 75%. In the core laboratory activities, the average percentage score was 69%, which also falls within the good category. However, several specific procedures showed relatively lower scores. These included the mixing of nitric acid with sulfuric acid, the mixing of benzene, and the addition of 10% NaOH solution, with percentages of 60%, 59%, and 59%, respectively, which are classified in the moderate category.

For the final stage of laboratory activities, the average percentage score reached 74%, indicating good safety practice implementation. Within this stage, the aspect related to proper storage of laboratory equipment demonstrated a very good performance with a percentage of 94%. In contrast, the management of solid laboratory waste showed a moderate level of implementation with a percentage of 55%. The final criterion assessed was the response to laboratory accidents, which obtained an average percentage score of 70% and was categorized as good. Nevertheless, the aspect related to handling exposure to toxic gases showed a relatively lower score of 46%, indicating that students' understanding and response to this type of emergency situation still require improvement.

The findings indicate that laboratory activities involving hazardous chemicals, particularly strong acids such as nitric acid and sulfuric acid, as well as organic solvents such as benzene, present significant chemical health risks. These substances are characterized by high corrosivity, flammability, and toxicity, which increase the potential for harmful exposure. From a chemical health perspective, the identified risks suggest the presence of both acute and chronic exposure [82]. Acute exposure may occur during improper handling of corrosive substances, leading to immediate effects such as chemical burns or irritation [83], [84]. In contrast, chronic exposure may result from repeated low-level contact with chemical vapors, particularly when personal protective equipment is not used consistently. Inconsistencies in the use of personal protective equipment further increase the likelihood of inhalation and dermal exposure [85]. This condition may not immediately result in observable health effects but can contribute to long-term health risks in laboratory environments where exposure occurs repeatedly.

Chemistry laboratories are specialized facilities equipped with instruments and chemical substances used to support experimental activities. These laboratories play an important role in facilitating laboratory work, experiments, and practicum activities in science education [1], [86]. Through laboratory activities, students are able to develop practical skills and deepen their understanding of chemical concepts. However, laboratory work also involves various potential hazards related to chemicals, equipment, and experimental procedures. Therefore, students must understand the proper use of laboratory equipment and consistently apply chemical health and safety principles before conducting experiments.

The results presented in Table 1 indicate that the implementation of chemical health and safety practices among sixth-semester Chemistry Education students is generally categorized as good, with an average percentage of 73%. This finding shows that most students are able to apply laboratory safety procedures during practicum activities. The relatively good level of safety implementation may be influenced by several supporting factors. One important factor is that students previously received training related to Chemical Safety and Security at the beginning of their practicum sessions. In addition, students may also obtain knowledge about laboratory safety from other learning resources such as textbooks and online materials.

Another factor that supports the implementation of laboratory safety practices is the development of a safety culture in the laboratory environment. A strong safety culture encourages all individuals involved in laboratory activities to prioritize safe working procedures. When safety awareness becomes an integral part of laboratory practice, it contributes to the creation of a safe and healthy learning environment [52]. Such a culture also promotes responsible laboratory behavior among students during experimental work [87]. As a result, students become more aware of potential hazards and more careful in handling chemicals and laboratory equipment.

Despite the generally positive results, the findings indicate that approximately 27% of students have not yet implemented chemical health and safety practices optimally. Several factors may contribute to this condition. One possible limitation is the availability of laboratory facilities that may not fully support the implementation of safety procedures. In addition, some students may overlook certain safety practices or underestimate the risks associated with laboratory activities [88]. This situation may increase the possibility of accidents or unsafe laboratory behavior if proper supervision is not maintained.

Potential hazards in chemistry laboratories may originate from chemical substances, experimental procedures, and the improper use of equipment [6], [7]. These hazards can lead to accidents, injuries, or other negative consequences when safety protocols are not followed carefully. Therefore, knowledge and awareness of laboratory safety are essential for minimizing risks during experimental activities [8]. Students must be trained to identify potential hazards and respond appropriately to emergency situations. Developing these competencies is important for ensuring safe and responsible laboratory practices in chemical education.

In this study, the evaluation of laboratory safety implementation was based on several indicators, including preparation, preparation of materials, core laboratory activities, final procedures, and responses to accidents. These indicators represent important stages in laboratory work where safety practices should be applied. The selection of these indicators allows a comprehensive evaluation of students' safety behavior during laboratory activities [89], [90]. To determine the appropriate practicum topics for observation, the researchers analyzed all laboratory modules used in the chemistry laboratory. This analysis aimed to identify practicum activities that involve significant laboratory skills and potential safety risks.

Based on this analysis, two practicum topics were selected for the observation process, namely the synthesis of nitrobenzene and the determination of moisture and ash content in biscuits. These experiments involve the use of hazardous chemicals and require careful handling procedures. In addition, both practicum topics require specific laboratory skills and strict adherence to safety protocols. Therefore, these activities provide an appropriate context for evaluating students' ability to apply chemical health and safety principles in laboratory settings. The results obtained from these observations provide valuable insights into students' competence in implementing laboratory safety practices.

The findings can be explained based on the chemical properties of the substances used in the laboratory. Nitric acid and sulfuric acid are highly corrosive substances that can cause severe chemical burns upon contact with skin or eyes. In addition, nitric acid acts as a strong oxidizing agent, increasing the risk of exothermic reactions when mixed improperly [91]. Benzene, on the other hand, is a volatile and toxic organic compound, and exposure through inhalation may pose significant health risks due to its carcinogenic nature [92]. The presence of these hazardous chemicals highlights the importance of exposure-based chemical safety management. The results suggest that laboratory safety practices should not only focus on procedural compliance but also emphasize the understanding of chemical hazard characteristics and their associated health risks. Therefore, integrating chemical hazard awareness into laboratory training is essential to reduce both acute and chronic exposure risks.

The findings of this study highlight the importance of safety culture and risk awareness in laboratory environments. International studies in chemical health and safety have shown that laboratory accidents are often associated with inadequate risk perception rather than a lack of safety procedures [49], [50]. In this study, although students generally followed safety procedures, lower performance in handling hazardous chemicals indicates a gap between safety knowledge and risk awareness. This gap suggests that students may comply with procedures without fully understanding the chemical hazards and associated exposure risks. Therefore, improving chemical safety education should focus not only on procedural training but also on enhancing students' ability to identify hazards, assess risks, and make safe decisions during laboratory activities.

This study provides important contributions to chemical health and safety practices in academic laboratory environments by demonstrating the application of a risk-based approach that integrates chemical hazard identification, exposure pathways, and task-based risk assessment. The findings offer practical insights for laboratory instructors and managers in prioritizing high-risk activities, particularly those involving corrosive, toxic, and flammable substances, and in improving exposure-oriented safety management. In addition, this study supports the development of more effective safety training by emphasizing the importance of linking procedural compliance with chemical risk awareness and safety culture.

However, this study has several limitations. The research was conducted in a single academic laboratory setting, which may limit the generalizability of the findings to other institutions with different laboratory conditions and safety practices. Furthermore, the assessment relied primarily on observational data and qualitative evaluation, which may be subject to observer bias and may not fully capture the actual magnitude of chemical exposure. The absence of quantitative exposure measurements, such as air concentration or biological monitoring, also limits the ability to assess the precise level of chemical health risks. Despite these limitations, the study provides a valuable foundation for future research aimed at strengthening exposure-based chemical safety evaluation in laboratory environments.

4. CONCLUSION

This study evaluated chemical health and safety practices in undergraduate chemistry laboratory practicum with a focus on chemical hazard identification and exposure risk assessment. The findings indicate that laboratory activities involving hazardous chemicals, particularly corrosive acids and flammable organic solvents, present significant risks of chemical exposure. These risks include both acute effects, such as chemical burns and irritation, and potential chronic health impacts due to repeated exposure. Although safety practices were generally implemented, inconsistencies in the use of personal protective equipment and handling procedures reduce the effectiveness of exposure prevention. The results highlight the importance of integrating chemical hazard characteristics and exposure pathways into safety evaluation. Overall, this study demonstrates that effective chemical health and safety management requires an exposure-based approach to minimize health risks in academic laboratory environments.

Furthermore, this study aligns with international chemical health and safety perspectives by demonstrating that effective laboratory safety management requires a risk-based approach that integrates hazard identification, exposure assessment, and safety behavior. The findings emphasize that strengthening risk awareness and safety culture is essential to prevent laboratory accidents and improve chemical health protection in academic environments. Future research is recommended to expand the application of risk-based chemical health and safety assessment across multiple laboratory settings to improve the generalizability of findings and to compare variations in chemical exposure risks. In addition, further studies should incorporate quantitative exposure measurements and real-time monitoring techniques to provide a more comprehensive evaluation of both acute and chronic chemical health risks in laboratory environments.

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AUTHOR CONTRIBUTIONS

Conceptualization, M.U. and V.M.; Methodology, M.U., V.M., and D.D.; Software, M.U.; Validation, M.U., V.M., and D.D.; Formal Analysis, M.U. and D.D.; Investigation, M.U.; Resources, V.M. and D.D.; Data Curation, M.U.; Writing – Original Draft Preparation, M.U.; Writing – Review & Editing, V.M. and D.D.; Visualization, M.U.; Supervision, V.M. and D.D.; Project Administration, M.U.; Funding Acquisition, V.M. and D.D.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

USE OF ARTIFICIAL INTELLIGENCE (AI)-ASSISTED TECHNOLOGY

The authors declare that no artificial intelligence (AI) tools were used in the generation, analysis, or writing of this manuscript. All aspects of the research, including data collection, interpretation, and manuscript preparation, were carried out entirely by the authors without the assistance of AI-based technologies.

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