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Evaluation of Chemical Health and Safety Management Using Task Risk Assessment in an Academic Chemical Process Laboratory

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ABSTRACT

Purpose of the study: This study aims to evaluate the implementation of a chemical health and safety management system in an academic chemical process laboratory by identifying chemical and process-related hazards, assessing task-related risks, and examining the adequacy of existing safety control measures in preventing chemical exposure and health risks.

Methodology: This study used a descriptive observational design. Tools included a structured laboratory safety checklist and a Task Risk Assessment matrix. Methods involved direct observation, document review, and semi-structured interviews. Reference standards included occupational safety and chemical health management principles. Data were analyzed qualitatively using risk categorization without specialized software.

Main Findings: Laboratory activities involved chemical, mechanical, thermal, electrical, and housekeeping hazards. Task Risk Assessment results indicated low, medium, and high-risk tasks, with high-risk activities predominantly associated with chemical exposure during handling and storage, as well as process-related hazards involving heated, pressurized, or moving equipment. Although engineering, administrative, and personal protective equipment controls were available, their implementation was inconsistent and not always aligned with the identified chemical health risks. Overall, the implementation of chemical health and safety management was partially aligned with recognized safety management principles.

Novelty/Originality of this study: This study provides task-level empirical evidence on chemical health and safety management in an academic chemical process laboratory and contributes to chemical health risk prevention by demonstrating how Task Risk Assessment can be applied to identify, prioritize, and control chemical exposure and process-related hazards in higher education laboratory environments.

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1. INTRODUCTION

Occupational safety is a critical concern in chemical engineering activities due to the inherent presence of hazardous chemicals, high-energy processes, and complex operational systems [1], [2]. In both industrial and academic environments, inadequate safety management can lead not only to immediate accidents but also to chemical exposure that poses serious risks to human health [3], [4]. Laboratory-related incidents continue to contribute significantly to preventable occupational injuries and chemical exposure events, underscoring the importance of structured safety management approaches rather than reliance on individual awareness alone [5], [6]. In this context, occupational safety is increasingly recognized as inseparable from chemical health protection, particularly in environments where hazardous substances are routinely handled.

Chemical health risks in laboratory environments arise primarily from exposure to hazardous substances through multiple routes, including inhalation of vapors and aerosols, dermal contact with liquids or contaminated surfaces, and accidental ingestion resulting from poor hygiene practices [7], [8]. Acute chemical exposure may result in burns, respiratory irritation, or poisoning, while chronic exposure—often underestimated in academic settings—can lead to long-term health effects such as respiratory disorders, dermatitis, neurological impairment, or carcinogenic outcomes [9], [10]. Improper chemical storage, inadequate ventilation, inconsistent use of personal protective equipment, and ineffective waste handling further exacerbate these risks [11], [12]. In academic laboratories, repeated low-level exposure during routine practical activities may accumulate over time, making chemical health risks particularly critical yet less visible compared to immediate physical injuries.

To systematically manage such risks, Occupational Safety and Health Management Systems have been widely adopted to control workplace hazards [13]-[15]. Frameworks such as ISO 45001 emphasize hazard identification, risk assessment, operational control, and continuous improvement as core elements of effective safety management [16], [17]. While these systems are well established in industrial contexts, their application often focuses on general occupational safety outcomes, with less explicit attention to chemical health risks and exposure pathways [18], [19]. Evidence from industrial sectors demonstrates that effective Occupational Safety and Health Management Systems implementation can reduce accident rates and improve safety performance; however, the extent to which these systems effectively address chemical health risks in academic laboratories remains insufficiently explored.

Academic chemical laboratories present unique chemical health and safety challenges compared to industrial environments [20], [21]. These laboratories involve frequent turnover of users, including students with varying levels of experience and limited awareness of chemical hazards [22], [23]. Practical learning activities require direct interaction with hazardous chemicals, heated systems, and pressurized equipment, often under time constraints and high instructional demands [24], [25]. In addition, academic laboratories may operate with limited resources, inconsistent supervision, and fragmented safety responsibilities. These conditions increase the likelihood of unsafe chemical handling practices and prolonged exposure risks if chemical health and safety management systems are not rigorously implemented.

Chemical process laboratories represent an even higher-risk academic environment because they simulate industrial-scale operations within an educational setting. Activities such as distillation, fluid flow experiments, heat transfer processes, and reaction systems involve simultaneous chemical, thermal, and mechanical hazards [26], [27]. From a chemical health perspective, these activities increase the potential for exposure to volatile substances, hot chemical streams, and process residues [28], [29]. Without systematic risk-based controls, both acute incidents and chronic exposure risks may escalate. Effective chemical health and safety management in such laboratories therefore requires task-specific risk assessment, exposure-oriented hazard identification, and consistent control implementation.

Despite the widespread adoption of Occupational Safety and Health Management Systems frameworks at the organizational level, empirical studies explicitly evaluating chemical health and safety management in academic chemical process laboratories remain limited [30], [31]. Existing research has largely focused on industrial settings or general laboratory safety practices, often emphasizing procedural compliance rather than exposure-based chemical health risks. In many academic institutions, chemical safety management relies heavily on standard operating procedures without formal, task-level evaluation of exposure risks, chronic health impacts, or control effectiveness [32], [33]. This gap highlights the lack of systematic evidence on how chemical health risks are identified, assessed, and managed in academic process-oriented laboratories.

The novelty of this study lies in its explicit focus on chemical health and safety at the task level within an academic chemical process laboratory. Unlike previous studies that primarily examine occupational safety management systems in industrial contexts or address laboratory safety in a general manner [34], [35], this research emphasizes chemical exposure pathways and process-related hazards inherent to educational process laboratories. By applying Task Risk Assessment to routine laboratory activities, this study provides empirical, task-based evidence on how chemical health risks are identified, prioritized, and controlled in an academic setting. This approach advances existing literature by bridging industrial risk assessment frameworks with chemical safety management and safety education in higher education laboratories.

The urgency of this research arises from the increasing intensity and complexity of chemical process activities in academic laboratories, coupled with the potential for both acute and chronic chemical health risks among laboratory users. Academic chemical process laboratories often involve repeated exposure to hazardous substances, heated systems, and process residues, while being operated by students with varying levels of safety awareness and limited professional experience. In the absence of systematic, exposure-oriented safety evaluation, these conditions may lead to under-recognized long-term health effects and unsafe work practices that persist beyond the academic environment. Therefore, timely evaluation of chemical health and safety management in academic process laboratories is essential not only to prevent chemical exposure and health risks but also to strengthen chemical safety culture and professional formation in future chemical engineers.

By providing a systematic, task-level assessment, this study seeks to generate empirical evidence that can support risk-based chemical safety management, enhance laboratory safety practices, and contribute to chemical health risk prevention and safety education in higher education laboratory environments.

2. RESEARCH METHOD

2.1. Research Design

This study employed a descriptive observational research design to evaluate the implementation of chemical health and safety management in an academic chemical process laboratory [36], [37]. The assessment focused on routine laboratory activities involving hazardous chemicals and process equipment, with particular attention to chemical exposure risks and process-related hazards. A task-based risk assessment approach was applied to systematically identify, assess, and prioritize chemical health risks associated with laboratory activities [38], [39].

The risk assessment process was guided by internationally recognized chemical safety standards, including the Globally Harmonized System of Classification and Labelling of Chemicals, chemical safety practices based on Safety Data Sheets, and laboratory safety requirements consistent with the Occupational Safety and Health Administration laboratory standard. This approach enabled a structured evaluation of chemical health risks rather than a general assessment of occupational hazards.

2.2. Unit of Analysis and Research Object

The unit of analysis in this study was an academic chemical process laboratory functioning as an educational and experimental work environment [20], [40]. The research objects consisted of chemical health and safety management components implemented within the laboratory, including chemical handling practices, storage systems, waste management procedures, and the operation of chemical process equipment.

Specific attention was given to chemical properties such as toxicity, flammability, corrosivity, and reactivity, as well as potential exposure pathways including inhalation, dermal contact, and accidental ingestion. In addition to technical hazards, managerial elements such as safety procedures, training practices, supervision mechanisms, and safety documentation related to chemical health protection were examined to assess how chemical safety principles were applied at the laboratory level [41], [42].

2.3. Data Collection Techniques and Research Instrument

Data were collected from both primary and secondary sources to ensure a comprehensive evaluation of chemical health and safety management practices. Primary data were obtained through direct on-site observations using a structured laboratory chemical safety checklist [43], [44]. The checklist was developed based on recognized chemical laboratory safety guidelines and standards, incorporating elements from the Globally Harmonized System of Classification and Labelling of Chemicals, Safety Data Sheet requirements, and established chemical laboratory safety practices. The checklist covered chemical labeling, chemical storage compatibility, ventilation adequacy, availability and use of personal protective equipment, emergency preparedness, and chemical waste handling practices. The content validity of the checklist was ensured by aligning all observation indicators with internationally accepted chemical safety standards, ensuring that the checklist accurately represented key aspects of chemical health and safety management.

In addition, semi-structured interviews were conducted with laboratory managers and technical personnel to obtain contextual information regarding chemical safety policies, training programs, supervision practices, and enforcement mechanisms [45], [46]. Secondary data were obtained from laboratory safety documentation, including chemical inventories, Safety Data Sheets, standard operating procedures, equipment records, and institutional chemical safety guidelines. Relevant scientific literature and chemical safety standards were also reviewed to support the evaluation framework and interpretation of findings. The instruments used in this study were designed to support the evaluation of chemical health and safety management in an academic chemical process laboratory. The primary instruments consisted of a structured chemical laboratory safety checklist, a task-based risk assessment matrix, and semi-structured interview guidelines. All instruments were developed based on recognized chemical health and safety standards and aligned with the objectives of identifying chemical hazards, assessing chemical exposure risks, and evaluating the adequacy of existing risk control measures.

To ensure consistency between the research objectives, data collection process, and research findings, an instrument grid was developed to map each instrument component to the evaluated variables, indicators, data sources, and expected outputs. This approach ensured that the collected data directly supported the identification of chemical and process-related hazards, task-based risk levels, and occupational safety management system implementation, as reflected in the research results. he alignment between research objectives, instruments, and findings is presented in the instrument grid shown in Table 1.

Tabel 1. Grid of Research Instruments Used

Research Variable	Indicator	Instrument	Data Source	Output Related to Results
Chemical health hazards	Type of hazardous chemicals used (toxic, flammable, corrosive, reactive)	Chemical laboratory safety checklist	Direct laboratory observation, chemical inventory, Safety Data Sheets	Identification of chemical hazards (Table on identified hazards)
Chemical exposure pathways	Inhalation, dermal contact, accidental ingestion during laboratory activities	Chemical laboratory safety checklist	Observation of laboratory activities and work practices	Description of chemical exposure risks
Process-related hazards	Heated systems, pressurized equipment, moving process units	Chemical laboratory safety checklist	Observation of process operations	Identification of thermal, mechanical, and process hazards
Task characteristics	Type and frequency of laboratory activities	Task-based risk assessment matrix	Observation and task documentation	Classification of laboratory tasks
Likelihood of chemical exposure	Frequency of task performance and exposure conditions	Task-based risk assessment matrix	Observation and expert judgment	Risk likelihood determination
Severity of chemical health impact	Potential acute and chronic health effects of chemical exposure	Task-based risk assessment matrix	Chemical properties, exposure characteristics	Risk severity determination
Task-based risk level	Combined likelihood and severity of chemical exposure	Task-based risk assessment matrix	Risk assessment results	Low, medium, and high risk task categories (Task risk assessment results table)
Engineering control measures	Ventilation systems, chemical storage cabinets, equipment guards	Chemical laboratory safety checklist	Observation and document review	Evaluation of existing risk controls
Administrative control measures	Standard operating procedures, safety rules, training practices	Chemical laboratory safety checklist and interview guide	Observation and interviews	Evaluation of safety management practices
Personal protective equipment	Availability and use of laboratory coats, gloves, and eye protection	Chemical laboratory safety checklist	Observation	Evaluation of personal protective equipment implementation
Safety management implementation	Hazard identification, training, supervision, monitoring	Interview guidelines and document review	Laboratory managers and safety documents	Occupational safety management system implementation level
Compliance with chemical safety standards	Alignment with chemical health and safety standards	Checklist comparison matrix	Observation and standards review	Gap analysis results
Improvement needs	Identified gaps and weaknesses	Gap analysis framework	Synthesized findings	Improvement recommendations

2.4. Data Processing and Analysis

Observational data were systematically compiled and organized to describe laboratory activities, chemical substances, and process operations associated with potential chemical health risks. Task-based risk assessment was conducted by evaluating each identified laboratory activity in terms of chemical hazard characteristics, likelihood of exposure, and severity of potential health consequences. The assessment explicitly incorporated chemical exposure severity by considering factors such as chemical toxicity, concentration, duration and frequency of exposure, and the effectiveness of existing control measures [47], [48]. Risk levels were determined using a standardized risk assessment matrix that integrated likelihood and severity to prioritize laboratory activities posing higher chemical health risks. This approach supported chemical health risk prioritization rather than merely providing general risk ranking. The adequacy of existing engineering controls, administrative controls, and personal protective equipment was subsequently evaluated in relation to the identified chemical health risk levels [18], [49].

2.5. Research Procedure

The research was conducted through a systematic sequence of steps designed to evaluate chemical health and safety management implementation in an academic chemical process laboratory. The procedure began with a review of relevant chemical safety standards, including the Globally Harmonized System of Classification and Labelling of Chemicals, Safety Data Sheet guidelines, and laboratory safety regulations, to establish evaluation criteria [50], [51]. On-site observations were then carried out to identify laboratory activities involving chemical handling and chemical process operations with potential exposure risks. A structured chemical safety checklist was applied to ensure consistent data collection across laboratory activities. Identified activities were documented in detail to support task-based risk analysis.

Subsequently, task-based risk assessment was performed by analyzing chemical hazard characteristics, exposure pathways, likelihood of occurrence, and severity of potential health effects for each activity. Existing control measures were evaluated for their effectiveness in preventing chemical exposure and health risks [52], [53]. Finally, observed practices were compared with recognized chemical health and safety standards to identify gaps and formulate recommendations aimed at improving chemical safety management and risk-based laboratory practices The flowchart of this research procedure can be seen in the image below:

Figure 1. Research procedure for evaluating occupational safety management system implementation in an academic chemical process laboratory

3. RESULTS AND DISCUSSION

3.1. Overview of Laboratory Activities and Hazard Characteristics

The academic chemical process laboratory facilitated various educational and analytical activities related to chemical process learning and research. The laboratory supported undergraduate practical courses in basic chemistry, organic chemistry, physical chemistry, and analytical chemistry. Each practical course consisted of approximately four modules, with each module comprising around seven experimental activities that required direct interaction with chemicals, laboratory equipment, and process units. In addition to teaching activities, the laboratory provided analytical services for final project research and commercial purposes, including UV–Visible spectrophotometry and other laboratory analyses. The laboratory also supported basic separation processes and operated a water purification system for producing distilled and demineralized water to support practical and research activities.

Table 2. Overview of Laboratory Activities

Laboratory Activity	Description
Undergraduate practical courses	Practical activities in basic chemistry, organic chemistry, physical chemistry, and analytical chemistry
Experimental modules	Approximately four modules per course, each consisting of around seven experiments
Analytical services	UV–Visible spectrophotometry and other analyses for final project and commercial purposes
Separation processes	Distillation, Soxhlet extraction, and column chromatography
Water production	Production of distilled and demineralized water with a capacity of approximately 1 L/hour

3.2. Identified Hazards in Laboratory Operations

Based on direct observations and checklist assessments, various occupational hazards were identified across laboratory activities. Chemical hazards were associated with the handling, storage, and use of chemicals during experimental preparation, analysis, and waste handling, with potential exposure through skin contact, inhalation, and spills. Equipment-related hazards were observed during the operation of laboratory instruments and process equipment involving moving parts, heat sources, pressure, and electrical power. Additional hazards were related to laboratory layout, housekeeping conditions, labeling practices, and inconsistent use of personal protective equipment. These hazards were identified at different stages of laboratory activities, including preparation, experimentation, analysis, and post-experiment cleaning.

Tabel 3. Identified Hazards in Laboratory Operations

Hazard Category	Source of Hazard	Potential Impact
Chemical hazards	Chemical handling, storage, spills, and waste management	Skin contact, inhalation exposure, chemical burns
Mechanical hazards	Rotating equipment, pumps, and moving parts	Cuts, entanglement, mechanical injury
Thermal hazards	Heated equipment, hot surfaces, distillation processes	Burns and heat-related injuries
Electrical hazards	Laboratory instruments and electrical installations	Electric shock and equipment failure
Housekeeping hazards	Poor workspace organization and cluttered areas	Slips, trips, and minor injuries

3.3. Task Risk Assessment Results

Task Risk Assessment was conducted for laboratory activities identified during the observation phase. Each task was assessed based on the likelihood of occurrence and the potential severity of its consequences. The results showed that laboratory tasks were distributed across low, medium, and high risk categories. High-risk tasks were mainly associated with chemical handling, heated processes, and operations involving pressurized or moving equipment. Medium-risk tasks were related to routine experimental procedures where control measures were present but not consistently implemented, while low-risk tasks were generally associated with non-operational or administrative activities.

Tabel 4. Task Risk Assessment Results

Risk Level	Description	General Characteristics of Tasks
High risk	High likelihood and/or severe consequences	Chemical handling, heated systems, pressurized or moving equipment
Medium risk	Moderate likelihood and consequences	Routine experiments with partial risk controls
Low risk	Low likelihood and minor consequences	Administrative or non-operational activities

3.4. Evaluation of Existing Risk Control Measures

The evaluation of existing risk control measures indicated that several hazard control strategies had been implemented within the laboratory. Engineering controls included ventilation systems, chemical storage cabinets, and physical guards on selected equipment. Administrative controls were present in the form of standard operating procedures, laboratory rules, and safety signage. Personal protective equipment such as laboratory coats, gloves, and safety goggles was available for laboratory users. However, observations indicated that the use of personal protective equipment was not consistently applied, and some control measures were not fully aligned with the risk levels identified through the Task Risk Assessment.

Tabel 5. Existing Risk Control Measures Identified

Type of Control	Implemented Measures	Observational Status
Engineering controls	Ventilation systems, storage cabinets, equipment guards	Available but not uniformly applied
Administrative controls	SOPs, laboratory rules, safety signage	Documented but inconsistently enforced
Personal protective equipment	Lab coats, gloves, safety goggles	Available but not consistently used

3.5. Occupational Safety Management System Implementation

The assessment of occupational safety management system elements showed varying levels of implementation within the laboratory. Hazard identification and risk assessment activities were conducted but were not systematically updated. Safety procedures and documentation were available, yet their application and monitoring were inconsistent. Training and supervision were present during laboratory practical sessions but were assessed as only partially adequate, particularly for higher-risk activities. Overall, the observed safety management practices demonstrated partial alignment with recognized occupational safety management system principles.

Tabel 6. Occupational Safety Management System Elements

Occupational Safety Management System Element	Observed Condition	Implementation Level
Hazard identification and risk assessment	Conducted but not systematically updated	Partially adequate
Safety procedures and documentation	SOPs and guidelines available	Partially adequate
Training and supervision	Present during practical sessions	Partially adequate
Monitoring and enforcement	Inconsistent implementation	Inadequate to partially adequate

The findings of this study demonstrate that academic chemical process laboratories present a complex occupational safety environment that shares characteristics with small-scale industrial operations. The presence of multiple hazard types within routine laboratory activities indicates that traditional laboratory safety approaches may be insufficient when applied to process-oriented educational settings. This supports previous research emphasizing that academic laboratories require structured safety management systems rather than reliance on procedural rules alone [54], [55]. A system-based approach is therefore essential to manage the dynamic risks associated with teaching and research activities. These findings reinforce the relevance of occupational safety management principles in academic chemical engineering laboratories.

The application of Task Risk Assessment in this study highlights the importance of task-level risk evaluation within laboratory environments. Unlike general hazard checklists, Task Risk Assessment provides a structured mechanism for identifying variations in risk associated with different laboratory activities [56], [57]. This approach aligns with international risk management frameworks that emphasize the evaluation of likelihood and severity as core components of effective hazard control. The identification of tasks requiring prioritized risk management suggests that laboratory safety programs should move beyond uniform control strategies. Instead, risk control measures should be proportional to the specific risk profile of each task.

The observed gaps between identified risks and existing control measures suggest limitations in the operationalization of safety management systems at the laboratory level [58], [59]. While engineering and administrative controls were present, their effectiveness depended largely on consistent implementation and user compliance. This finding reflects broader challenges reported in academic safety literature, where formal safety documentation does not always translate into safe work practices. Effective occupational safety management therefore requires not only the availability of control measures but also mechanisms for monitoring, enforcement, and continuous improvement [60], [61]. These elements are central to the successful implementation of Occupational Safety Management System frameworks such as ISO 45001.

From an organizational perspective, partial alignment with occupational safety management principles indicates the need for stronger integration of safety into laboratory governance. Safety responsibilities in academic laboratories are often distributed among multiple stakeholders, including instructors, laboratory technicians, and students [62], [63]. Without clearly defined roles and accountability mechanisms, safety management practices may become fragmented. Strengthening supervisory structures and reinforcing safety leadership are therefore critical to improving overall safety performance [64], [65]. This supports the view that safety culture plays a significant role in the effectiveness of laboratory safety management systems.

The findings also have implications for chemical engineering education. Academic laboratories serve not only as operational workspaces but also as environments for professional formation. Exposure to systematic safety management practices during practical training can influence students' safety awareness and professional behavior [66], [67]. Integrating risk-based safety management into laboratory instruction may therefore contribute to the development of safety-conscious future engineers. This educational dimension further underscores the importance of implementing robust occupational safety management systems in academic settings.

Overall, this study highlights the value of systematic evaluation of occupational safety management systems in academic chemical process laboratories. By applying a structured risk assessment approach and examining safety management practices at the operational level, the study contributes to the limited empirical literature on laboratory safety management in higher education [68], [69]. The findings suggest that continuous evaluation and refinement of safety management practices are necessary to address the evolving risks associated with academic laboratory activities. These insights provide a foundation for enhancing occupational safety performance in similar educational laboratory environments.

The task-based risk assessment results indicate that laboratory activities categorized as high risk are predominantly associated with chemical exposure and process-related hazards. These risks are mainly linked to direct handling of hazardous chemicals, heating processes, and inadequate control measures during routine laboratory activities [70], [71]. From a chemical health perspective, the identified risks suggest a potential for both acute and chronic exposure. Acute exposure risks are associated with short-term contact with corrosive or toxic substances during handling and transfer activities, while chronic exposure risks may arise from repeated low-level exposure due to insufficient ventilation, inconsistent use of personal protective equipment, and improper chemical storage practices.

Inconsistencies in the use of personal protective equipment further amplify the potential health impacts of chemical exposure [48], [72]. Inadequate or improper use of laboratory coats, gloves, and eye protection increases the likelihood of dermal contact and accidental ingestion, while insufficient respiratory protection may elevate inhalation risks. These conditions may not immediately result in observable health effects but can contribute to long-term occupational health problems, particularly in academic laboratory environments where exposure occurs repeatedly over extended periods.

The findings also reflect broader issues related to chemical safety culture in academic laboratory settings. Although safety procedures and basic protective measures are formally available, their inconsistent implementation suggests that chemical health and safety practices are not yet fully embedded as routine behavior. This condition indicates that safety compliance is often perceived as procedural rather than preventive, particularly among laboratory users who prioritize experimental outcomes over systematic risk control.

The application of task-based risk assessment in this study demonstrates its important role in strengthening chemical safety culture by shifting attention from general hazard awareness to exposure-based risk control. By linking laboratory tasks directly to chemical properties, exposure pathways, and health consequences, the risk assessment process supports more informed decision-making and encourages proactive control measures [56], [73]. This approach highlights the value of structured risk assessment as an educational and managerial tool for improving chemical health protection in academic laboratories.

From an educational perspective, the results underscore the need to integrate chemical health and safety principles more explicitly into laboratory-based learning activities [74], [75]. The presence of high-risk tasks related to chemical exposure suggests that laboratory users may have limited awareness of long-term health risks associated with repeated exposure to hazardous substances. Strengthening chemical safety education, particularly through the practical application of task-based risk assessment, can enhance students' understanding of chemical hazards and foster responsible laboratory behavior [76], [77]. Incorporating exposure-based risk evaluation into laboratory instruction may also improve students' ability to recognize hazardous conditions, select appropriate control measures, and comply consistently with personal protective equipment requirements. Therefore, the findings support the integration of chemical health and safety training as a core component of academic laboratory education rather than as supplementary safety instruction.

The results of this study are consistent with previous research that highlights chemical exposure as a dominant risk factor in laboratory environments, particularly in academic settings. Earlier studies have reported that inadequate ventilation, inconsistent use of personal protective equipment, and insufficient chemical waste management are common contributors to chemical health risks [78], [79]. Similar findings have emphasized that repeated low-level exposure to hazardous chemicals poses significant long-term health concerns, even when acute incidents are relatively rare [80], [81]. Furthermore, previous research has demonstrated that task-based risk assessment is an effective approach for identifying exposure-specific risks and prioritizing control measures in laboratory environments. The alignment between the findings of this study and existing literature strengthens the validity of the results and confirms the relevance of exposure-oriented risk assessment for improving chemical health and safety management in educational laboratories.

The findings of this research contribute to chemical health and safety practice by providing empirical evidence of exposure-based risks in an academic chemical process laboratory. The study demonstrates how task-based risk assessment can be used not only to identify hazardous activities but also to prioritize chemical health risks and evaluate the adequacy of existing control measures. These results may inform laboratory managers, educators, and policy developers in designing more effective chemical safety management strategies and educational interventions.

However, this study also has several limitations. The assessment was conducted in a single academic laboratory, which may limit the generalizability of the findings to other laboratory settings with different chemical processes and safety cultures. In addition, the risk assessment relied on observational data and qualitative judgments, which may be influenced by observer interpretation. Despite these limitations, the results provide a valuable foundation for further research and highlight the importance of exposure-focused risk assessment in academic chemical laboratories.

4. CONCLUSION

This study aimed to evaluate the implementation of chemical health and safety management in an academic chemical process laboratory by identifying chemical and process-related hazards, assessing task-based risks, and examining the adequacy of existing control measures in preventing chemical exposure and health risks. The results show that laboratory activities involve diverse hazards, with high-risk tasks predominantly associated with chemical exposure and process-related operations. These findings indicate that chemical health risks in the laboratory are not limited to immediate incidents but also include the potential for repeated exposure that may affect long-term health.

The task-based risk assessment successfully identified and prioritized laboratory activities with higher chemical health risks by considering chemical properties, exposure pathways, and potential health impacts. This confirms that the applied method is effective for evaluating chemical health risks at the activity level and provides a clearer basis for risk prioritization compared to general hazard identification alone. The evaluation of existing control measures indicates that, although engineering controls, administrative procedures, and personal protective equipment are available, their implementation is not consistently aligned with the identified risk levels. Such inconsistencies reduce the effectiveness of chemical exposure prevention and highlight the need for stronger alignment between risk assessment results and control practices.

Overall, this study achieves its objective by providing a systematic evaluation of chemical health and safety management in an academic chemical process laboratory. The findings offer empirical evidence to support exposure-oriented risk prioritization and demonstrate the importance of task-based risk assessment in strengthening chemical health risk prevention and safety management practices in higher education laboratory environments. Future studies are recommended to apply task-based chemical health and safety evaluation across multiple academic chemical laboratories to enhance the generalizability of findings and enable comparative analysis of chemical exposure risks. In addition, further research should incorporate quantitative exposure assessment methods to complement observational risk evaluation and provide deeper insight into the magnitude of acute and chronic chemical health risks.

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AUTHOR CONTRIBUTIONS

Conceptualization, W.W., E.S., and D.E.S.-S.; Methodology, W.W. and E.S.; Software, W.W.; Validation, W.W., E.S., and D.E.S.-S.; Formal Analysis, W.W.; Investigation, W.W. and D.E.S.-S.; Resources, E.S. and D.E.S.-S.; Data Curation, W.W.; Writing – Original Draft Preparation, W.W.; Writing – Review & Editing, E.S. and D.E.S.-S.; Visualization, W.W.; Supervision, E.S.; Project Administration, W.W.

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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