Investigating Safety Behavior, Accidents, and Safety Standards: The Role of Strategic Design and Education in Enhancing Laboratory Safety

Duangporn Garshasbi[1*], Pattadon Sukkapan[1], Jureebhorn Kaewjunda[1], Krisada Masomboon[1], Kanyakorn Kunwaneeworaya[1], Supunnee Pladsrichuay[2] and Sasawat Pengpae[2]

[1]Faculty of Science, Chandrakasem Rajabhat University

[2]Faculty of Humanities and Social Sciences, Chandrakasem Rajabhat University

Corresponding Author Email : duangporn.g@chandra.ac.th

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Abstract

This study aims to analyze unsafe behaviors and examine their association with laboratory accident occurrence by comparing physical and chemical safety behaviors among first-year science students at Chandrakasem Rajabhat University. A mixed-method research design was employed with a sample of 111 participants. Data were collected using structured questionnaires, behavioral observation checklists, and self-reported accident experience records. Descriptive statistics and the Chi-square test were used for data analysis at a significance level of 0.05.

The findings indicated a high level of compliance with chemical safety standards, with 96.4% of students avoiding the use of expired chemicals and 81.1% properly storing chemicals. However, inconsistencies were observed in physical safety behaviors. Specifically, 59.5% of students reported inconsistent use of personal protective equipment (PPE), and 40.5% admitted to using mobile phones during laboratory experiments. The Chi-square analysis revealed a statistically significant association between unsafe physical behaviors and laboratory accident occurrence (χ^2 = 6.841, df = 1, p = 0.009), whereas unsafe chemical behaviors were not significantly associated with accidents (χ^2 = 1.152, p = 0.283). These results demonstrated a structural distinction between chemical safety compliance and physical safety behaviors. Strategic design components—such as spatial layout planning, hazard zoning, safety signage, and emergency evacuation routes—were found to strongly support chemical safety compliance. In contrast, improving physical safety behaviors required behavioral reinforcement through practice-oriented training, structured supervision, and integration within the institutional Safety Management System. The findings could

inform the development of laboratory design guidelines, behavior-focused safety training curricula, and PPE monitoring tools to enhance the sustainability of laboratory safety systems in higher education contexts.

Keywords: Laboratory Safety, Safety Non-compliance, Physical Hazards, Chemical Hazards, Safety Management System

1. Introduction

Education in science, particularly in chemistry, relies heavily on laboratory-based instruction, where students translate theoretical knowledge into practical experience through experiments involving chemicals, laboratory glassware, electrical devices, and analytical instruments. These laboratories are essential components of educational built environments, providing experiential learning that enhances scientific competence. However, due to the presence of hazardous substances, reactive materials, and complex equipment, chemistry laboratories are inherently high-risk environments that require structured and systematic safety management [1, 2].

Extensive research has shown that unsafe human behavior is a leading cause of laboratory accidents in academic institutions [3, 4]. Studies examining university laboratory incidents highlight the role of behavioral non-compliance, inadequate supervision, and weaknesses in safety culture as key contributors to injury and property damage [5, 6]. According to hazard theory, laboratory risks can be categorized into physical, chemical, ergonomic, electrical, and general safety hazards [7]. In many safety frameworks, ergonomic and electrical risks are treated as subsets of broader physical hazards [8]. For analytical clarity, this study therefore classifies unsafe behaviors into two principal domains: behaviors contributing to physical hazards and behaviors contributing to chemical hazards.

Unsafe behaviors related to physical hazards include inconsistent use of personal protective equipment (PPE), distractions such as mobile phone use, horseplay during laboratory operations, careless handling of equipment, and failure to inspect tools before use. Unsafe behaviors associated with chemical hazards include failure to read chemical labels before use, improper chemical storage, inadequate spill response, unsafe handling practices, and other deviations from chemical safety protocols [9, 10]. While both categories present significant risks, the extent to which each domain directly contributes to laboratory accident occurrence has not been systematically compared.

Despite the growing body of international literature on laboratory safety, several important research gaps remain. First, many prior studies treat unsafe behavior as a generalized construct without distinguishing between unsafe physical behaviors and unsafe chemical behaviors when analyzing accident causation [3, 9-10]. Limited empirical evidence exists that quantitatively compares the distinct statistical effects of these two behavioral domains on accident incidence. Second, within the context of Thai higher education institutions—particularly public universities—research has primarily focused on safety awareness, compliance perception, or chemical management practices

[4] rather than examining the direct relationship between categorized unsafe behaviors and laboratory accident occurrence. Third, although strategic laboratory design and safety education are widely recognized as critical elements of risk management, few studies have empirically evaluated their differentiated influence on physical versus chemical safety compliance in educational laboratory environments.

From a safety science and management perspective, laboratory safety should be understood as an integrated system combining environmental control mechanisms and behavioral reinforcement strategies. Strategic Design represents a structural risk mitigation approach that optimizes spatial organization, equipment placement, safety signage visibility, and emergency route accessibility to reduce the probability of human error . Education and training function as behavioral interventions that strengthen safety awareness, risk perception, and compliance consistency. However, the comparative effectiveness of these system-level approaches in influencing distinct categories of unsafe behavior remains underexplored in academic laboratory contexts.

To provide structural context for interpreting behavioral findings, the laboratory environment examined in this study was referenced against established laboratory safety evaluation frameworks, including criteria comparable to the ESPReL Checklist, which assesses infrastructure adequacy, safety equipment availability, emergency preparedness systems, and workspace organization. Although a full architectural audit was beyond the scope of this research, this benchmarking approach provides a structured reference for understanding the interaction between environmental conditions and observed safety behaviors.

In response to these identified gaps, this study investigates the safety behaviors of undergraduate science students during chemical laboratory activities by systematically comparing unsafe physical behaviors and unsafe chemical behaviors and examining their statistical relationship with laboratory accident occurrence. Furthermore, the study evaluates the relative roles of Strategic Design and Education in enhancing safety compliance. By integrating hazard theory [7, 8], behavioral safety principles [9, 10] and systemic safety design approaches, this research contributes to the advancement of laboratory safety management knowledge and provides evidence-based insights applicable to educational laboratory environments beyond a single institutional setting.

2. Scope of the Study

This study focuses on examining the safety behaviors of undergraduate science students during chemical laboratory activities at Chandrakasem Rajabhat University. The scope includes identifying behaviors that contribute to physical and chemical hazards, assessing students' compliance with standard safety practices such as PPE use, equipment handling, and chemical management, and analyzing the relationship between unsafe behaviors and laboratory accidents. Data were collected using questionnaires, observational checklists, and reports of accident experiences, limited to students enrolled in laboratory-based science courses. The study also considers students'

perceptions of strategic design and safety education, though it does not involve a full architectural or environmental assessment of laboratory facilities.

3. Literature Review

The review is organized into three core areas, including safety behavior in chemical laboratory environments, unsafe behaviors associated with physical and chemical hazards, and the role of strategic design and education in enhancing safety, as follows:

3.1 Safety Behavior in the Chemical Laboratory Environment

Safety behavior refers to actions or responses to various situations or stimuli that adhere to safety regulations, with the aim of preventing accidents, injuries, fatalities, occupational diseases, as well as loss or damage to property [11-13]. Such behavior reflects an intention to perform tasks within a safe environment or to minimize exposure to potential hazards. Specifically, safety behavior in the chemical laboratory environment refers to actions, decision-making, and practices undertaken carefully and responsibly, aiming to prevent accidents and minimize risks associated with the proper and effective handling of chemical and physical hazards.

3.2 Unsafe Behavior related to Physical Hazards and Chemical Hazards

Unsafe behavior refers to actions or decisions that violate established safety protocols and increase the likelihood of accidents or injuries [14, 15]. In chemical laboratory environments, such behaviors span both physical and chemical hazards [6]. Physical-hazard behaviors include mishandling equipment, improper or inconsistent use of PPE, unsafe storage of sharp or heavy objects, failure to manage spills or broken glassware, and disregard for fire or electrical safety. Chemical-hazard behaviors involve improper handling, labeling, and storing of chemicals, incorrect operation of fume hoods, and negligence in responding to spills or exposures, all of which heighten risks of burns, toxic inhalation, explosions, and fires [16]. These unsafe behaviors arise from factors such as inadequate safety training, complacency, time pressure, risk underestimation, and weak organizational safety culture, making it essential to address these root causes to reduce laboratory accidents and strengthen overall safety management [17].

3.3 Laboratory Safety Through Strategic Design and Education

Laboratory safety is a critical component of risk management in academic institutions, particularly in chemical laboratory environments where hazardous substances, reactive processes, and complex equipment coexist. From a safety science and management perspective, effective laboratory safety relies on the integration of structural controls and behavioral interventions. Two key components underpin this integrated approach: strategic design and education [18].

Strategic design refers to the deliberate planning and organization of laboratory infrastructure to reduce hazard exposure and support safe operational behavior. It encompasses both architectural and functional elements of laboratory environments, including spatial configuration, equipment placement, ventilation systems, and emergency preparedness infrastructure [19]. Well-designed laboratory environments reduce reliance on individual vigilance by

embedding safety principles into the physical layout, thereby minimizing the probability of human error.

International laboratory safety standards, including OSHA laboratory safety guidelines and ISO-based occupational health and safety management systems, emphasize several essential components of strategic laboratory design [17, 18]. These include:

(1) hazard zoning and segregation of incompatible chemical processes;

(2) adequate ventilation systems and compliance with fume hood performance standards;

(3) clearly marked and unobstructed emergency egress routes;

(4) standardized safety signage and hazard communication systems;

(5) accessible emergency response equipment such as eyewash stations, safety showers, and fire extinguishers; and

(6) systematic risk assessment integrated into laboratory layout planning.

These structural components function as primary prevention mechanisms by reducing exposure probability, mitigating consequence severity, and providing environmental cues that promote safe behavior.

Importantly, strategic design may influence different categories of unsafe behavior in distinct ways. Design elements such as ventilation systems, hazard zoning, and chemical segregation primarily support chemical hazard control and reduce risks related to improper storage, spill mismanagement, and hazardous substance exposure. In contrast, spatial organization, clear safety signage, and unobstructed pathways more directly influence physical safety compliance by reducing tripping hazards, equipment misuse, and unsafe movement within the laboratory. This differentiation provides a theoretical basis for examining how strategic design may disproportionately affect physical versus chemical safety behaviors—an issue empirically investigated in the present study.

While structural controls form the foundation of laboratory safety, education serves as a complementary behavioral intervention. Education ensures that laboratory users understand hazard characteristics, internalize safety norms, and consistently follow established safety protocols [20]. Effective safety education programs typically include regular training sessions, safety briefings, emergency response simulations, and reinforcement of proper personal protective equipment (PPE) usage and chemical handling procedures [21].

Empirical evidence suggests that safety education and training significantly reduce unsafe behaviors and accident rates, particularly when training addresses both cognitive understanding and practical skill development [22]. Education strengthens compliance in key areas such as proper PPE usage, chemical labeling and storage practices, emergency response procedures, and incident reporting [23]. However, educational interventions may exert varying degrees of influence across different hazard domains. For example, training may more strongly impact behavioral compliance related to physical safety practices, such as PPE use and safe equipment handling, whereas structural design elements may play a more decisive role in chemical hazard control.

When combined, strategic design and education create a holistic and mutually reinforcing safety system. Strategic design provides structural safeguards that reduce environmental risk factors, while education enhances individuals' ability to recognize hazards and respond appropriately. This integrated framework supports the development of a proactive laboratory safety culture, in which both environmental conditions and user behavior are systematically aligned to prevent accidents rather than merely react to them. The present study builds upon this theoretical foundation by empirically examining how these two system-level components influence distinct categories of unsafe behavior and laboratory accident occurrence.

3.4 Synthesis of Literature and Research Gaps

The literature reviewed in the preceding sections consistently emphasized three core dimensions of laboratory safety: (1) unsafe behavior as a primary contributor to accident causation, (2) the classification of hazards into physical and chemical domains, and (3) the importance of systemic interventions such as strategic design and safety education in promoting compliance. Collectively, these studies established that laboratory accidents arise from the interaction between behavioral factors and environmental conditions rather than from isolated events [3, 9-10].

However, a critical synthesis of the literature revealed several unresolved issues that warranted further investigation. First, although unsafe behavior was widely acknowledged as a major cause of laboratory incidents, there was a distinct lack of empirical studies that systematically compared the differential effects of unsafe physical behaviors and unsafe chemical behaviors on actual laboratory accident rates. Most existing research examined unsafe behavior as a generalized construct, evaluated specific hazard types independently, or focused on qualitative descriptions of safety culture, without conducting statistical analyses that directly compared these two behavioral domains in relation to accident occurrence.

Second, while hazard classification frameworks clearly distinguished between physical and chemical risks [7, 8], behavioral studies rarely investigated whether these categories exhibited different patterns of accident contribution or varying levels of statistical association with incident frequency. Without such differentiation, safety interventions may remain broadly defined and insufficiently targeted to specific hazard mechanisms.

Third, although strategic design and education were consistently recognized as complementary pillars of laboratory safety management [17-23], the existing body of literature insufficiently analysed how these system-level factors differentially or disproportionately influence physical and chemical safety compliance. Structural design elements—such as ventilation systems, hazard zoning, and equipment placement—may primarily support chemical hazard control by reducing exposure pathways. In contrast, educational interventions may exert stronger influence on individual behaviors associated with physical safety practices, such as PPE compliance and safe equipment handling. Nevertheless, empirical evidence systematically examining these differentiated influences remained limited.

Therefore, a clear research gap exists at the intersection of hazard categorization, unsafe

behavior analysis, and systemic safety interventions. There is a need for empirical research that (1) systematically compares unsafe physical and unsafe chemical behaviors in relation to laboratory accident rates, and (2) evaluates how strategic design and education contribute differently to these distinct domains of safety compliance.

The present study addresses this gap by statistically examining the relationship between categorized unsafe behaviors and laboratory accident occurrence while simultaneously assessing the relative influence of strategic design and education on physical and chemical safety behaviors. By integrating hazard theory, behavioral safety principles, and systemic safety management frameworks, this research advances laboratory safety scholarship and provides a more nuanced understanding of how structural and behavioral factors interact within academic laboratory environments.

4. Research Method

4.1 Case Study Profile

The study was conducted within the chemical laboratories of the Faculty of Science at Chandrakasem Rajabhat University, located in Bangkok, Thailand. These laboratories serve as core facilities for undergraduate students enrolled in science-related programs, including Chemistry, Biology, Environmental Science, and Physics. Students use these laboratories extensively for practical experiments, coursework, and research projects as part of their academic curriculum.

The laboratories are equipped with essential scientific instruments necessary for a variety of chemical experiments. Facilities include chemical storage rooms, fume hoods for ventilation and the safe handling of volatile substances, and designated areas for waste disposal. Personal protective equipment (PPE) such as lab coats, gloves, and safety goggles are provided to students to support safe laboratory practices.

Two chemical laboratory rooms were included in this study. Each laboratory room has an approximate usable area of 17.14 square meters (3.71 × 4.62 meters), resulting in a combined total laboratory area of approximately 34.28 square meters. Each room accommodates up to 30 students per practical session. Laboratory instruction is organized into four groups per day (two morning and two afternoon sessions), allowing the facilities to accommodate a maximum of 120 students daily (30 students × 4 groups), depending on academic scheduling requirements.

The laboratory facilities are designed and managed in alignment with national laboratory safety regulations and reference internationally recognized safety management frameworks, including ISO-based occupational health and safety management systems and laboratory design guidelines [17], [18]. Core strategic design elements include hazard zoning, fume hood placement to optimize ventilation flow, accessible emergency exits, visible safety signage, and readily available emergency equipment such as eyewash stations and fire extinguishers.

These structural elements reflect the principles of Strategic Design discussed in Section 3.3 and provide a practical context for examining how environmental layout and safety infrastructure interact with student safety behavior.

Despite the presence of standard safety infrastructure, challenges remain in ensuring consistent safety behavior among students. Laboratory sessions often involve multiple groups working simultaneously, which increases the complexity of maintaining strict adherence to safety protocols. As such, these laboratories present a realistic and practical setting for investigating the relationship between safety behavior, laboratory accidents, and the effectiveness of strategic design and education in promoting a safer learning environment.

4.2 Research Design

This study employs a mixed-methods research design, integrating quantitative and qualitative approaches to provide a comprehensive analysis of laboratory safety behavior.

The quantitative component consisted of structured questionnaires and statistical analysis to examine the relationship between categorized unsafe behaviors and laboratory accident occurrence. The qualitative component involved thematic analysis of open-ended responses to explore students' perspectives on strategic design and safety education.

The questionnaire was used to measure self-reported safety behaviors and perceptions. The observational checklist was employed to record real-time behavioral compliance during laboratory sessions. Accident records were analyzed to examine the statistical association between unsafe behaviors and actual incident occurrence. The integration of these methods enhances methodological triangulation and strengthens analytical validity.

4.3 Participants and Sampling Technique

The population of this study consisted of first-year undergraduate students enrolled in laboratory-based courses requiring the use of chemical laboratories during the academic year. A total of 111 students participated in the study, representing the following academic programs: Food Science and Technology (n = 20), Civil Engineering and Construction Management (n = 38), Chemistry (n = 14), and General Science (n = 39).

A census sampling approach was employed, whereby all eligible first-year students enrolled in laboratory-based courses during the data collection period were invited to participate. Eligibility criteria required participants to be actively enrolled in a program that included chemical laboratory coursework and to provide voluntary informed consent. Students who were absent on the day of data collection or who did not complete the questionnaire were excluded from the analysis.

Participation was voluntary, and informed consent was obtained from all participants prior to data collection.

4.4 Research Instruments

4.4.1 Questionnaire

The questionnaire was developed based on hazard theory and laboratory safety literature. Items were categorized into two domains: unsafe physical behaviors and unsafe chemical behaviors. Responses were measured using a structured Likert-scale format. The questionnaire was divided into four sections including Section A focused on demographic information and general experiences with laboratory accidents, Section B examined the perceived causes of accidents, Section

C explored behaviors associated with physical hazards, and Section D addressed behaviors contributing to chemical hazards.

4.4.2 Observational Checklist

Direct observations were conducted during laboratory practical sessions to record instances of unsafe behavior in real time. An observational checklist was developed based on established hazard theory [7], [8] and laboratory safety management literature. The checklist incorporated both behavior-related indicators (e.g., failure to wear personal protective equipment) and situational risk factors (e.g., improper chemical storage or unsafe handling practices).

Unsafe behavior was operationally defined as any observable action that deviated from established laboratory safety protocols. Behavioral indicators were categorized into two domains: unsafe physical behaviors and unsafe chemical behaviors. The frequency of each unsafe behavior was systematically recorded during structured observation sessions.

Observations were conducted across eight laboratory sessions over multiple days to enhance reliability and reduce situational variability. To minimize the Hawthorne effect, observations were performed unobtrusively and at a distance. Repeated exposure to observation sessions allowed students to become accustomed to the observer's presence, thereby reducing behavior modification associated with awareness of being observed.

4.4.3 Data Validity and Reliability

To ensure methodological rigor, content validity was evaluated by three experts in chemical laboratory safety and occupational safety management. The Index of Item-Objective Congruence (IOC) was assessed for each item to ensure alignment with research objectives. Items meeting acceptable criteria were retained. The Content Validity Index (CVI) was calculated to assess the level of agreement among experts, confirming satisfactory content validity of the instrument.

Prior to full-scale data collection, pilot testing was conducted with a group of undergraduate laboratory users to evaluate item comprehensibility, wording clarity, and response consistency. Minor revisions were implemented based on participant feedback to eliminate ambiguity and enhance measurement precision.

Internal consistency reliability was assessed using Cronbach's Alpha, yielding a coefficient of $\alpha = 0.86$. This value exceeds the commonly accepted threshold of 0.70, indicating high internal consistency and reliability of the measurement instrument.

To enhance external applicability, the categorization of unsafe behaviors was grounded in established hazard theory [7], [8], and the strategic design constructs were aligned with internationally recognized laboratory safety standards [17], [18]. This theoretical grounding strengthens the generalizability of the findings to other academic institutions with comparable laboratory environments.

4.4.4 Data Analysis

Data from the survey and observation were analyzed using descriptive and inferential statistics. Descriptive statistics were used to summarize the demographics of the sample, the

frequency of unsafe behaviors, and the rate of safety protocol compliance. Inferential statistics, including Chi-square tests, were employed to examine the relationship between unsafe behaviors and laboratory accidents. The analysis aimed to identify significant patterns or correlations between specific unsafe behaviors (e.g., improper chemical handling or mishandling of equipment) and the occurrence of accidents. Additionally, the research utilized thematic analysis to identify recurring themes in students' responses related to their understanding of safety measures and the perceived effectiveness of safety education and protocols.

Quantitative data were analyzed using statistical software (SPSS version 24). Descriptive statistics were used to summarize behavioral frequencies. Inferential analysis, including Chi-square tests, was conducted to examine associations between categorized unsafe behaviors and laboratory accident occurrence. Statistical significance was determined at $\alpha = 0.05$.

Qualitative data from open-ended responses were analyzed using thematic analysis to identify recurring patterns related to strategic design and safety education.

5. Results and Discussions

5.1 Demographic Characteristics and Accident Experience

The results revealed that the majority of respondents were 18 years old, totaling 68 individuals (61.30%), followed by 19-year-olds, totaling 43 individuals (38.70%). Regarding gender, most respondents were female, accounting for 67 individuals (60.40%), while male respondents accounted for 44 individuals (39.60%). In terms of academic major, most respondents were enrolled in the General Science Education program under the Faculty of Science, totaling 39 individuals (35.10%). This was followed by students majoring in the Environment and Safety Management program, with 38 individuals (34.20%). Additionally, 20 respondents (18.00%) were from the Food Science and Technology program, and 14 respondents (12.60%) were from the Chemistry Education program, all within the Faculty of Science.

Demographic characteristics were relevant to laboratory safety research because age, academic discipline, and early-stage laboratory exposure may influence safety awareness, risk perception, and behavioral compliance. As first-year students, participants may have limited prior experience in formal chemical laboratory environments, which could affect their familiarity with laboratory protocols and hazard recognition. Furthermore, differences across academic programs may reflect variations in laboratory intensity, prior safety training, and exposure to risk management principles. Understanding these demographic factors provided important contextual information for interpreting patterns of unsafe behavior and accident occurrence.

Regarding accident experience, Table 1 presents the number and percentage of respondents who reported injuries sustained specifically in university-level chemistry laboratory settings. The majority of students (89.20%) reported never having experienced an accident in the laboratory, while 10.80% indicated that they had encountered at least one laboratory-related

incident. Only accident experiences occurring within the university laboratory context were included in inferential analysis to ensure consistency with the scope of this study

Table. 1 Number and Percentage of Respondents Regarding Experiences of Accidents in the Chemistry Laboratory.

Accident Experience Topics	Frequency (n)	Percentage (%)
Experience of Laboratory Accidents		
Never experienced	99	89.20
Experienced	12	10.80
Number of Accidents Experienced		
1 time	8	66.70
2 times	3	25.00
3 times	1	8.30
Types of Injuries (n = 12)		
Slip/Fall	6	50.00
Cuts from Sharp Objects	2	16.70
Objects Falling on Body Parts	3	25.00
Chemical Splash	1	8.30
Fire Burns	0	00.00
Electric Shock	0	00.00
Injured Body Parts (n = 12)		
Hands and Fingers	7	58.30
Arms	1	8.30
Legs	1	8.30
Feet and Toes	3	25.00
Eyes	0	00.00
Head	0	00.00
Property Damage (n = 12)		
No damage	8	66.70
Damaged	4	33.30
Total	**111**	**100.00**

Table 2 presents the frequency and percentage distribution of reported contributing factors associated with accidents occurring in the university-level chemistry laboratory. The findings indicated that the most frequently reported contributing factor was a crowded and limited workspace (44.00%). This suggested that spatial constraints may have restricted students' movement and increased the likelihood of unintended contact with equipment or hazardous materials. The second most common contributing factor was horseplay during laboratory operations (36.00%), reflecting behavioral non-compliance and insufficient adherence to safety protocols.

Other reported factors included lack of caution (8.00%), inadequate lighting (4.00%), improper arrangement of equipment or chemicals (4.00%), and the use of defective equipment, tools, or materials (4.00%). Although these factors were reported less frequently, they represent important environmental and procedural vulnerabilities within the laboratory environment.

Overall, the findings demonstrated that both environmental constraints and behavioral risk factors contributed to accident occurrence. While spatial limitations increased exposure risk, unsafe behaviors such as horseplay directly elevate the probability of injury. These results reinforced the importance of integrating effective strategic laboratory design with active behavioral supervision and safety enforcement mechanisms.

The results presented in Tables 2–4 are derived from self-reported questionnaire responses completed by all 111 participants. These findings reflected students' reported perceptions and behaviors rather than direct observational counts. Observational checklist data were collected separately across eight laboratory sessions to validate behavioral patterns; however, they were not the primary source of the reported frequency distributions.

Table. 2 Percentage of Causes of Injuries or Accidents in the Chemistry Laboratory.

Cause of Injuries/Accidents	Frequency (n)	Percentage (%)
Crowded and limited working area	11	44.00
Horseplay during laboratory operations	9	36.00
Lack of caution	2	8.00
Inadequate lighting	1	4.00
Improper arrangement of equipment/chemicals	1	4.00
Defective equipment/ tools/ materials	1	4.00
Total	25	100.00

Noted: The total frequency (n = 25) exceeds the number of students who experienced accidents (n = 12) because multiple contributing factors could be reported for a single incident.

5.2 Analysis of Unsafe Behaviors Leading to Physical and Chemical Hazards

5.2.1 Survey Questionnaire

Table 3 provides a detailed overview of the frequency with which respondents engage in behaviors that contribute to physical hazards during laboratory work. The table categorizes various unsafe behaviors based on the respondents' reported frequency, ranging from "Always" to "Never." For example, 42.3% of students reported disturbing others during experiments "sometimes," while 40.5% frequently used mobile phones during experiments ("almost every time"). Additionally, 27% of participants reported using equipment carelessly "sometimes," with another 32.4% stating that it occurred "rarely." The table highlights the varying degrees of unsafe behaviors, with certain actions, such as disturbing others and using mobile phones, occurring more frequently than others.

The table also sheds light on other behaviors that could contribute to physical hazards, such as improper use of equipment and failure to check equipment conditions. For instance, 39.9% of students reported checking equipment conditions "rarely," and 33.3% engaged in improper use of equipment "rarely." Interestingly, behaviors like not wearing personal protective equipment were reported very infrequently, with only 0.9% of students admitting to doing so regularly. Furthermore, very few students engaged in activities like taking antihistamines while working (71.2% reported never doing this), and there was no report of alcohol consumption before or during laboratory work. The data underscores the variability in unsafe behaviors and suggests areas where safety education and interventions could be beneficial.

Table. 3 Number and Percentage of Respondents Classified by Behaviors Leading to Physical Hazards.

Behavior Leading to Physical Hazards	Always (%)	Almost Always (%)	Sometimes (%)	Rarely (%)	Never (%)	Total (n)
1. Disturbing others during experiments	2 (1.8)	22 (19.8)	47 (42.3)	31 (27.9)	9 (8.1)	111
2. Not checking equipment condition	3 (2.7)	23 (20.7)	31 (27.9)	44 (39.9)	10 (9.0)	111
3. Improper use of equipment	1 (0.9)	1 (0.9)	5 (4.5)	37 (33.3)	67 (60.4)	111
4. Not wearing personal protective equipment	0 (0.0)	1 (0.9)	21 (18.9)	66 (59.5)	23 (20.7)	111
5. Taking antihistamines/cold	0 (0.0)	1 (0.9)	1 (0.9)	30 (27.0)	79 (71.2)	111

Behavior Leading to Physical Hazards	Always (%)	Almost Always (%)	Sometimes (%)	Rarely (%)	Never (%)	Total (n)
medicine while working						
6. Careless use of equipment	1 (0.9)	7 (6.3)	30 (27.0)	36 (32.4)	37 (33.3)	111
7. Insufficient rest before working	0 (0.0)	6 (5.4)	28 (25.2)	56 (50.5)	21 (18.9)	111
8. Using mobile phones during experiments	11 (9.9)	45 (40.5)	36 (32.4)	11 (9.9)	8 (7.2)	111
9. Horseplay during laboratory work	0 (0.0)	2 (1.8)	16 (14.4)	76 (68.5)	17 (15.3)	111
10. Drinking alcohol before/during laboratory work	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	111 (100.0)	111

5.2.2 Unsafe behaviors related to Chemical Hazard

Table 4 presents a breakdown of the frequency with which respondents engage in behaviors that could lead to chemical hazards during laboratory work. The table categorizes unsafe behaviors based on how often they occur, ranging from "Always" to "Never." One notable behavior is "not reading chemical labels before use," with 34.2% of participants admitting to doing this "sometimes" and 33.3% doing so "rarely." Another behavior, "failing to report chemical spills/leaks," was reported as "rarely" by 47.7% of respondents and "sometimes" by 7.2%. Importantly, more serious safety violations, such as "smoking during chemical operations" and "using the mouth to pipette chemicals," were reported as never occurring, with 100% of participants stating they never engaged in these highly dangerous behaviors.

The table also shows that some other behaviors, such as "not following prohibitory signs and warnings," were reported with relatively low frequency, as 36.9% of students indicated they did so "rarely," and 58.6% said they never engaged in this behavior. Similarly, 51.4% of respondents reported "not turning off lights/unplugging after use" as a "rare" practice, while 38.7% indicated they never did so. Regarding chemical storage, only 17.1% of respondents reported improper chemical storage "rarely," and 81.1% never engaged in such behavior. Additionally, the use of expired chemicals was reported as a rare occurrence, with 96.4% of students stating they never used expired chemicals. This data highlights a generally positive safety attitude, but it also suggests that occasional lapses in following safety protocols still persist.

Table. 4 Number and Percentage of Respondents Classified by Behaviors Leading to Chemical Hazards.

Behavior Leading to Chemical Hazards	Always (%)	Almost Always (%)	Sometimes (%)	Rarely (%)	Never (%)	Total (n)
1. Not reading chemical labels before use	5 (4.5)	18 (16.2)	38 (34.2)	37 (33.3)	13 (11.7)	111
2. Not turning off lights/unplugging after use	0 (0.0)	2 (1.8)	9 (8.1)	57 (51.4)	43 (38.7)	111
3. Not following prohibitory signs and warnings	1 (0.9)	0 (0.0)	4 (3.6)	41 (36.9)	65 (58.6)	111
4. Smoking during chemical operations	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	111 (100.0)	111
5. Using mouth to pipette chemicals	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	111 (100.0)	111
6. Failing to report chemical spills/leaks	0 (0.0)	1 (0.9)	8 (7.2)	53 (47.7)	49 (44.1)	111
7. Improper chemical storage	0 (0.0)	0 (0.0)	2 (1.8)	19 (17.1)	90 (81.1)	111
8. Using expired chemicals	0 (0.0)	0 (0.0)	2 (1.8)	2 (1.8)	107 (96.4)	111

5.3 Statistical Association Between Unsafe Behaviors and Accident Occurrence

In this section, the relationship between unsafe behaviors and laboratory accidents is examined. The hypotheses are as follows:

- H_0: There is no significant relationship between unsafe behavior and the incidence of laboratory accidents among chemistry students.
- H_1: There is a significant relationship between unsafe behavior and the incidence of laboratory accidents among chemistry students.

To test these hypotheses, a Chi-square test was conducted, and the results are summarized in Table 5.

Table 5 presents the Chi-square test results for two types of unsafe behaviors—unsafe physical behavior (such as horseplay, phone use, and distractions) and unsafe chemical behavior (such as mislabeling or mishandling chemicals).

For unsafe physical behavior, the Chi-square value (χ^2) was 6.841, with 1 degree of freedom (df = 1), and the p-value was 0.009. Since the p-value is less than the common significance level of 0.05, it indicates a statistically significant relationship between unsafe physical behaviors and the occurrence of laboratory accidents. This suggests that engaging in unsafe physical behaviors increases the likelihood of accidents in the laboratory setting.

For unsafe chemical behavior, the Chi-square value (χ^2) was 1.152, with 1 degree of freedom (df = 1), and the p-value was 0.283. Since the p-value exceeds 0.05, there is no statistically significant relationship between unsafe chemical behaviors and laboratory accident occurrence.

It should be noted that the number of reported chemical-related injuries was limited (n = 1). Therefore, statistical inferences regarding the relationship between chemical unsafe behaviors and accident occurrence should be interpreted cautiously. The absence of a statistically significant association may reflect limited incident frequency rather than definitive evidence of no relationship. Future research involving larger multi-institutional samples or longitudinal data collection is recommended to increase statistical power and further validate these findings.

Table. 5 Chi-Square Test Results of Relationship Between Unsafe Behavior and Incidence of Laboratory Accidents.

Unsafe Behavior Type	χ^2	df	*p*-value	Interpretation
Unsafe Physical Behavior (e.g., horseplay, phone use, distractions)	6.841	1	0.009	Significant Relationship
Unsafe Chemical Behavior (e.g., mislabeling, mishandling chemicals)	1.152	1	0.283	No Significant Relationship

5.4 Compliance with Standard Safety Practices in the Chemistry Laboratory

Compliance with standard safety practices in the chemistry laboratory varied among the students, with certain areas showing strong adherence to safety protocols, while others revealed notable lapses in behavior.

In terms of chemical safety, the majority of students demonstrated strong compliance with essential safety rules. For instance, 81.1% of respondents reported always storing chemicals properly, which reflects good practices in maintaining a safe laboratory environment. Additionally, 96.4% of students avoided using expired chemicals, a key safety measure to prevent accidents

caused by degraded or ineffective substances. These figures suggest that students were generally conscientious about chemical safety and followed critical safety standards related to chemical handling.

However, when it comes to physical safety practices, there were more frequent lapses. While 59.5% of students reported "rarely" wearing personal protective equipment (PPE) during laboratory work, this indicates that a significant portion of students did not consistently adhere to the use of essential protective gear, potentially increasing the risk of physical harm. Additionally, while 68.5% of students "rarely" engaged in horseplay during laboratory work, a concerning 14.4% admitted to engaging in it "sometimes." Such behaviors can cause distractions or accidents in the lab, highlighting the need for better enforcement of safety rules related to physical conduct. Regarding equipment use, 60.4% of students stated they "never" failed to follow the equipment manuals, showing a relatively strong commitment to safe and proper equipment handling. On the whole, only 11.7% of students reported "never reading chemical labels" before use, which suggests that the majority were generally good about reading and understanding labels, contributing to safer chemical handling.

These findings indicate that students tend to comply more consistently with chemical safety standards than with physical safety practices, which may reflect differences in awareness, training, or enforcement of safety protocols. The observed lapses in physical safety, such as inconsistent use of PPE and occasional horseplay, suggest areas where further attention and improvement are needed to ensure comprehensive safety compliance in the laboratory.

5.5 The Role of Strategic Design and Education in Enhancing Laboratory Safety

This study identified strategic design and education as key factors influencing laboratory safety among science students at Chandrakasem Rajabhat University. Using thematic analysis, the research explored recurring themes in students' responses regarding their understanding of safety measures and the perceived effectiveness of safety education and protocols. This qualitative approach allowed for a deeper insight into how physical environments and educational interventions impact students' safety behaviors.

The findings reveal that specific laboratory design elements—such as the organization of workspaces, placement of warning signs, and accessibility of emergency evacuation routes—significantly support safer laboratory practices. Although the study did not comprehensively evaluate every aspect of design, the thematic analysis indicated a clear correlation between students' awareness of safety procedures and their interaction with the physical laboratory environment. Well-organized spaces and visible safety signage were commonly associated with reduced distractions and greater adherence to safety protocols.

During the study period, the readiness and operational condition of laboratory safety equipment were maintained according to institutional laboratory management procedures. Essential infrastructure, including fume hoods, emergency showers, eyewash stations, and fire extinguishers, was routinely inspected prior to laboratory sessions to ensure functional availability. Although

independent calibration assessments were beyond the scope of this study, the laboratories operated under standard institutional maintenance protocols. This ensured that observed unsafe behaviors were not attributable to equipment malfunction, thereby strengthening the internal validity of the findings.

Despite generally strong compliance with chemical safety standards, inconsistencies were evident in physical safety practices. For example, 59.5% of students reported that they "rarely" used personal protective equipment (PPE), highlighting a concerning gap between available safety infrastructure and student behavior. This suggests that while strategic design facilitates a safer environment, it alone is insufficient to ensure full compliance without continuous educational reinforcement.

From a behavioral psychology and learning theory perspective, this gap between knowledge and physical safety compliance can be explained by the distinction between cognitive understanding and habitual behavior formation. According to behavior-based safety principles and social learning theory [11-13], knowledge acquisition does not automatically translate into sustained behavioral change. Chemical safety practices are often procedural and cognitively driven (e.g., reading labels, following chemical handling protocols), whereas physical safety behaviors—such as consistent PPE use and minimizing distractions—require habit formation, environmental reinforcement, and social modeling. Physical behaviors are strongly influenced by peer norms, perceived immediacy of risk, and situational awareness. Without structured reinforcement, supervision, and repeated practice, students may possess adequate chemical knowledge yet fail to consistently apply physical safety behaviors. This explains why effective chemical education does not necessarily guarantee full compliance with physical safety practices.

Education therefore emerged as a crucial component in promoting laboratory safety. Thematic analysis revealed that while students demonstrated awareness of chemical hazards, many lacked consistent application of physical safety behaviors, including regular PPE usage, proper handling of equipment, and avoidance of distractions such as mobile phone use. The findings suggest that safety education requires enhancement through more interactive, practice-oriented methods. Incorporating hands-on demonstrations, scenario-based simulations, routine safety drills, and active learning strategies may strengthen behavioral reinforcement and promote long-term safety habits.

These results are consistent with prior research emphasizing that a well-structured laboratory environment reduces chemical safety risks, whereas sustained improvements in physical safety behavior rely more heavily on behavioral reinforcement and educational strategies. Effective laboratory safety therefore requires an integrated approach in which environmental design supports compliance while educational interventions cultivate behavioral consistency.

To address the identified gaps, several recommendations are proposed. First, education and training programs should expand their focus beyond chemical safety procedures to include consistent reinforcement of physical safety behaviors through experiential learning approaches.

Second, laboratory designs should be further optimized to maintain clutter-free workspaces, enhance visibility of safety signage, and ensure accessible emergency equipment. Third, monitoring and enforcement mechanisms for PPE compliance should be strengthened through structured supervision and accountability systems. Finally, cultivating a proactive safety culture is essential, encouraging peer accountability, mentorship initiatives, and open reporting of unsafe behaviors.

Integrating strategic laboratory design with comprehensive, practice-oriented education and structured behavioral reinforcement mechanisms can significantly enhance student safety behavior. These combined efforts contribute to a safer laboratory environment, reduce accident risk, and promote a sustainable culture of safety awareness within academic institutions.

Although this study was conducted within a single university laboratory context, the behavioral classifications were grounded in established hazard theory and internationally recognized laboratory safety standards. Therefore, the identified patterns distinguishing physical and chemical unsafe behaviors may be applicable to other academic institutions with comparable laboratory environments. Nevertheless, differences in laboratory size, supervision intensity, and institutional safety culture may influence behavioral outcomes. Future multi-institutional studies are recommended to strengthen external validity and broader generalizability.

5.6 Limitations of the Study

This study was conducted within a single university context, which may limit the generalizability of findings to institutions with different laboratory sizes, hazard profiles, or safety cultures. The laboratories examined primarily supported undergraduate teaching activities and may not reflect higher-risk research laboratories involving advanced chemical processes. Additionally, accident data were based partly on self-reported experiences, which may introduce recall bias. Although observational methods were implemented to strengthen reliability, real-time observation may not capture all unsafe behaviors across all sessions. Future research should expand to multiple universities and laboratory types to enhance external validity.

6. Conclusions

This study aimed to assess the safety behavior of science students during chemical laboratory activities, focusing on behaviors contributing to physical and chemical hazards. The results revealed that while students generally demonstrated good compliance with chemical safety practices, physical safety behaviors exhibited more inconsistencies. Specifically, students adhered to chemical safety standards such as proper chemical storage and avoiding expired chemicals, with high compliance rates. However, behaviors such as wearing personal protective equipment (PPE) and avoiding distractions like phone use or horseplay showed notable lapses, indicating that physical safety practices require greater attention.

The study also highlighted the role of strategic design and education in promoting laboratory safety. Effective laboratory design elements, including clear safety signage, organized workspaces, and designated escape routes, contributed positively to safety behaviors, particularly in terms of

chemical safety. However, the findings suggest that these environmental factors alone are not sufficient to fully address physical safety concerns. Education and training emerged as critical components in reducing unsafe behaviors, with a focus on reinforcing the importance of PPE, safe equipment use, and the avoidance of distractions in the laboratory setting.

7. Recommendations

Based on the findings of this study, several strategic recommendations are proposed to enhance laboratory safety management at the institutional level.

7.1 Policy-Level Recommendation

Institutions should consider implementing Digital Safety Monitoring systems or real-time behavioral tracking mechanisms to reduce unsafe physical behaviors such as horseplay, improper equipment handling, and distraction during laboratory operations. Real-time monitoring tools, including digital check-in systems, automated PPE compliance alerts, and sensor-based supervision technologies, may strengthen behavioral accountability and reduce accident risk.

7.2 Design-Level Recommendation (Strategic Design Enhancement)

Laboratory spatial design should incorporate structural enforcement mechanisms, such as designated PPE compliance checkpoints at laboratory entry points and clearly defined mobile phone–restricted zones. Designing transitional buffer areas where students are required to wear appropriate protective equipment before entering operational zones may promote automatic compliance and reduce behavioral lapses.

7.3 Educational and Research Recommendation

Future research should incorporate qualitative methodologies, such as in-depth interviews or focus group discussions, to explore the underlying psychological and contextual factors influencing inconsistent PPE use. Although students may demonstrate adequate chemical knowledge, qualitative inquiry may reveal deeper motivational, social, or cultural factors affecting physical safety compliance.

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