

Article

Chemical Safety in Academic Laboratories: Awareness, Attitudes, and Practices Among Higher Education Students

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Abstract

Higher education institutions, particularly those with teaching and research laboratories, play an important role in transmitting knowledge and attitudes regarding chemical safety to their students. As such, this study aims to assess the knowledge and attitudes of higher education students across different study programs regarding laboratory chemical safety. A cross-sectional study was conducted using a questionnaire adapted and translated into Portuguese. The instrument comprised twenty-seven questions and was distributed to students enrolled in undergraduate and graduate programs that include laboratory practices in their curricula in March and July of 2025. A total of 284 students participated in the study, divided among the different study programs (CTeSP = 4.2%; Bachelor's = 70.4%; Master's = 21%; Doctorate = 4.2%). The results showed that, although a large percentage of students have a high level of knowledge, their attitudes are not always the most appropriate, which could jeopardize their safety and that of those around them. Our findings revealed that there is room for curriculum adjustments. Early exposure to chemical and laboratory safety concepts can promote the development of students' awareness and future professionals' competence. Integrating safety modules into education may enhance knowledge and skills for making informed decisions that reduce accidents/incidents in laboratory environments.

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1. Introduction

The laboratory is the foundation on which higher education institutions base their teaching activities, serving as a vital platform for training high-quality talent and building a national innovation system. With the expansion of scientific theory and the development of science and technology, university laboratories are more engaged in cutting-edge research. However, this procedure often involves investigating new materials or methods that may present unknown dangers. These problems constitute substantial impediments

to safety management in university laboratories [1]. The Occupational Safety and Health Administration (OSHA) has recorded several potential hazards in laboratories, including chemical, biological, physical, and safety hazards. Laboratory activities, such as academic and research activities, expose laboratory employees to potential hazards and increase the risk of incidents [2]. However, because these teaching and research activities are typically conducted on a small scale or for a limited period, people often underestimate or even ignore the associated risks [1].

Fires and explosions caused by chemical use are among the incidents that can occur in academic laboratories. The Chemical Safety Board of the United States of America (USA) has recorded several cases of fires and explosions in university laboratories that have resulted in serious injuries [2].

Several innovative initiatives at universities and research institutes have aimed to improve safety management and prevent laboratory accidents, including implementing safety programs, conducting safety meetings, and highlighting the unique requirements of chemical management [3].

One of the main challenges in promoting safety in academic laboratories concerns the users themselves. Undergraduate students, for the most part, begin laboratory activities with limited practical experience and insufficient training in safety procedures. Additionally, it is frequently observed that professors and researchers place greater importance on scientific productivity than on strict adherence to safety standards, a phenomenon exacerbated by the intense competitiveness associated with obtaining funding and scientific production in high-pressure academic environments [4].

This study aims to evaluate higher education students' knowledge, attitudes, and practices regarding chemical safety in laboratory environments. Specifically, it seeks to (i) assess students' familiarity with chemical hazard symbols and emergency procedures, (ii) examine their attitudes towards compliance with laboratory safety rules, (iii) analyze their self-reported safety practices and, (iv) analyze the psychometric properties of the Portuguese version of the questionnaire. The findings are expected to identify gaps in safety awareness and behavior, thereby informing the development of targeted training initiatives and institutional strategies to strengthen laboratory safety culture.

2. Materials and Methods

2.1. Study Context and Setting

This cross-sectional study was conducted across several Portuguese higher education institutions, including universities and polytechnic institutes. It encompassed courses that integrate practical laboratory classes in areas such as chemistry, biology, histology, and other life and health sciences. In Portugal, higher education is organized into three main cycles of study, in accordance with the Bologna Process. The first cycle corresponds to undergraduate education and includes Short Cycle Higher Technical Professional Programs (CTeSP), typically lasting two years and oriented toward practical and professional training, as well as Bachelor's degrees. The second cycle comprises Master's degrees, which usually last one to two academic years and aim to deepen scientific, technical, and professional competencies, often integrating research or advanced professional practice components. Some fields also offer Integrated Master's degrees, combining first and second cycles into a single program with a typical duration of five to six years. The third cycle corresponds to Doctoral programs, which are research-oriented and typically last three to four years, with a focus on the development of original scientific research and advanced methodological skills.

Although there is no evidence that laboratory safety training is mandatory across study cycles and programs, it is essential that students know and understand the standards governing their safe use.

2.2. Sample

A convenience sampling strategy was applied, with all students enrolled in undergraduate and graduate programs that include laboratory practices in their curricula. This non-probabilistic approach was deemed appropriate given the exploratory nature of this study and the practical constraints of reaching a broad cross-sectional sample.

2.3. Survey Instrument

The questionnaire was adapted from the original survey by Al-Zyoud et al. [5], which comprised 27 questions organized into five sections. The Section 1 comprised five demographic questions, including the following variables: sex, age group, study program, academic year, and prior training in laboratory safety. The second included nine pictograms that were required to match the corresponding hazard. In the Section 3, responses to statements were rated on a five-point Likert scale, and the attitude score was calculated by assigning 1 to “strongly disagree”, 2 to “disagree”, 3 to “neutral”, 4 to “agree”, and 5 to “strongly agree”.

The fourth consists of four questions, three of which were on the Likert scale, where “never” was assigned with 1, “sometimes” with 2, and “always” with 3, and one was a multiple-choice question. This section was designed to assess students’ laboratory practices. In the Section 5, we included five multiple-choice questions that assessed students’ knowledge and familiarity with emergency equipment and procedures [1]. The Portuguese version of the questionnaire is provided in Appendix A.

2.4. Translation Procedure and Cultural Adaptation

To ensure the instrument was linguistically and culturally appropriate for Portuguese higher education students, a comprehensive translation and adaptation process was undertaken. After obtaining authorization from one of its authors to use the questionnaire for translation, adaptation, and cultural validation, we followed the guidelines proposed by Beaton et al. [6].

Two translators, with distinct professional backgrounds, carried out the first two translations of the instrument into Portuguese. They were unfamiliar with the questionnaire and, consequently, with the study’s objectives, resulting in two independent translations. Subsequently, the two translations were compared by a committee of experts composed of two PhDs in Occupational Health and Safety, one PhD in Chemistry, and two Occupational Health and Safety practitioners. This process aimed at ensuring that the instrument was conceptually equivalent, culturally appropriate, and suitable for practical application.

Based on the analysis of the differences between the two translations, a single consensus version was produced. Consequently, this version, adapted for Portuguese culture, was sent to a third party who was also fluent in English and had not participated in the initial translation, and thus was unfamiliar with the questionnaire. The document was then translated back into its original language—English.

To complete the process, the committee analyzed the translation and compared it with the original to determine whether any significant differences would jeopardize the study.

2.5. Data Collection and Analysis

This study was conducted in two main phases. The first phase involved the translation, cultural adaptation, and content validation of the questionnaire originally developed by Al-Zyoud et al. [5], designed to assess higher education students' perceptions, knowledge, and practices regarding chemical risk in laboratory environments. The translation followed a forward–backward procedure conducted by a committee of experts to ensure semantic and conceptual equivalence. The same expert panel subsequently reviewed the adapted version to establish content validity. Prior to full implementation, a pilot test was conducted with 10 students from different study programs to evaluate the clarity of instructions, item comprehension, and adequacy of response time. Minor linguistic adjustments were introduced based on participants' feedback.

The second phase consisted of administering the final version of the questionnaire to students enrolled in laboratory-based courses at Portuguese higher education institutions. The survey was distributed anonymously through an online platform. Participants were recruited via institutional email communication and direct invitation during laboratory classes. Participation was voluntary, and informed consent was obtained prior to questionnaire completion.

After data collection, statistical analyses were performed using IBM SPSS Statistics version 29.0. The analysis comprised descriptive, inferential, and psychometric procedures. Descriptive statistics included absolute and relative frequencies for sociodemographic and academic variables (gender, age, study program, academic year, and previous laboratory safety training). The Knowledge Score was computed as the sum of correct responses to the nine knowledge items (Section 2 of the questionnaire) and treated as a discrete quantitative variable. For certain comparative analyses, the Knowledge Score was categorized into tertiles (low, medium, and high knowledge levels). Given the non-normal distribution of the data, non-parametric tests were applied. Non-parametric tests were selected because several variables did not meet the assumptions of normality required for parametric statistical procedures. These tests are particularly appropriate for ordinal variables and non-normally distributed data, as they compare the distribution of observations between groups using rank-based methods rather than raw means. Spearman's rank correlation coefficient was used to examine associations between the Knowledge Score and other questionnaire dimensions, including risk perception, attitudes, and reported practices. This coefficient measures the strength and direction of monotonic relationships between ordinal or non-normally distributed variables. Group comparisons were conducted using the Mann–Whitney U test (for two independent groups) and the Kruskal–Wallis test (for three or more independent groups). These non-parametric tests evaluate whether statistically significant differences exist between groups by comparing the mean ranks of observations rather than the arithmetic means, making them suitable for ordinal data and non-normally distributed variables. For the section assessing attitudes toward chemical safety, an Exploratory Factor Analysis (EFA) was conducted using Principal Component Analysis (PCA) as the extraction method. PCA was used for data reduction, reducing many variables into fewer components that maximize variance, whereas EFA was used to identify latent constructs (factors) that explain correlations among variables. Sampling adequacy was assessed using the Kaiser–Meyer–Olkin (KMO) measure and Bartlett's test of sphericity. The number of retained factors was determined based on Kaiser's criterion (eigenvalues > 1) and inspection of the scree plot. Factorial validity was considered acceptable when standardized factor loadings (λ) were ≥ 0.50 [7]. Internal consistency was assessed using Cronbach's alpha, with values ≥ 0.70 considered indicative of acceptable reliability [8]. Cronbach's alpha is a commonly used reliability coefficient that assesses the degree to which items within a scale measure the same underlying construct. Finally, descriptive analyses (frequencies and percentages) were conducted to

characterize students' reported practices and knowledge regarding emergency equipment and accident scenarios.

2.6. Ethical Considerations

The study was approved by the Ethics Committee of the School of Health at the Polytechnic of Porto (Reference CE0018F, 25/02/2025), in compliance with all ethical and legal standards applicable to research involving human subjects. The study was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki. In accordance with the General Data Protection Regulation (GDPR), participation was voluntary and confidential, and no personal or identifiable data were collected.

3. Results

3.1. Demographic Data

A total of 284 higher-education students from various study programs and scientific fields participated in this study. Participants were enrolled in laboratory-based programs within health-related (e.g., Biomedical Sciences, Environmental Health, Pharmacy, Dental Medicine). They applied science areas (e.g., Biotechnology, Chemistry, Biology, Environmental Sciences, Microbiology), including undergraduate and postgraduate courses involving practical laboratory activities. The sociodemographic data are presented in Table 1.

Table 1. Frequency distribution of students by demographics (N = 284).

Variable	Frequency	Percent
Gender		
Male	72	25.3
Female	207	72.9
Other	3	1.0
Prefer not to say	2	0.7
Age Group		
18–20	108	38.0
21–25	128	45.0
26–29	15	5.3
+30	33	11.6
Study Program		
CTeSP	12	4.2
Bachelor's Degree (University)	56	19.7
Bachelor's Degree (Polytechnic)	144	50.7
Master's Degree (University)	20	7.0
Master's Degree (Polytechnic)	29	10.2
Integrated Master's Degree (University)	11	3.8
Doctorate (University)	12	4.2
Doctorate (Polytechnic)	0	0
Academic Year		
Year 1	80	28.1
Year 2	77	27.1
Year 3	70	24.6
Year 4	54	19.0
Year 5	3	1.0
Year 6	0	0

Have you ever had training on laboratory safety procedures? (Including modules/classes on the subject as part of a Curricular Unit of your course)		
Yes	229	80.6
No	55	19.4

Regarding gender, female students predominate, comprising 72.9% of the sample, whereas 25.3% identified as male. Regarding age, the majority of students were in the 21–25 (45%) and 18–20 (38%) age ranges, indicating a predominantly young sample in the early years of their academic journey. The 26–29 and ≥ 30 age ranges represented 5.3% and 11.6%, respectively. Regarding the study program, most participants were enrolled in undergraduate courses at polytechnic institutions (50.7%) and at universities (19.7%). The distribution by academic year revealed a greater concentration in the first three years: 1st year (28.1%), 2nd year (27.1%), and 3rd year (24.6%).

Finally, regarding prior training in laboratory safety (including content taught in curricular units or thematic modules), 80.6% of participants reported having received such training, whereas 19.4% reported no prior experience in this area.

3.2. Assessment of Students' Familiarity and Understanding of Chemical Hazards Warning Signs

Section 2 of the instrument aimed to assess students' ability to recognize nine pictograms found in the GHS. Each correct answer was assigned a value of 1, and incorrect answers a value of 0. Summing the correct answers yielded the variable Knowledge_Score, which takes values between 0 and 9.

Differences in Knowledge Score by academic cycle and academic year were examined using nonparametric tests, as described in the Section 2.

Table 2 presents the descriptive statistics for each pictogram evaluated. The sample mean is 7.56 (SD = 1.74), indicating a high overall level of familiarity with hazard pictograms. However, the range is 0 (minimum possible) to 9 (maximum possible), with some students unable to correctly identify any symbol. This finding raises questions about user safety in the laboratory.

Table 2. Descriptive Statistics for Correct Identification of Hazard Pictograms and Total Knowledge Score.

		Statistics									Knowledge_Score
		Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	
N	Valid	284	284	284	284	284	284	284	284	284	284
	Missing	0	0	0	0	0	0	0	0	0	0
	Mean	0.76	0.94	0.82	0.95	0.89	0.55	0.87	0.77	0.99	7.5563
	Std. Deviation	0.425	0.231	0.385	0.209	0.312	0.498	0.337	0.421	0.102	1.73521
	Minimum	0	0	0	0	0	0	0	0	0	0.00
	Maximum	1	1	1	1	1	1	1	1	1	9.00

Most students correctly identified between 7 and 9 hazard pictograms, indicating a high level of knowledge. However, lower scores indicate asymmetries in visual safety literacy. The most recognized pictograms were Toxic (99%), Corrosive (95%), and Irritant (94%), while Combustible showed the lowest success rate (55%).

To assess whether there were statistically significant differences in visual knowledge across study cycles, the nonparametric Kruskal–Wallis test was applied, as the dependent variable (Knowledge Score) was not normally distributed.

Initially, the variable “Study Program” included seven distinct categories, distinguishing academic degrees by institution type (university vs. polytechnic). However, for this analysis, equivalent categories were merged, integrating the same academic cycles (e.g., bachelor’s or master’s degrees), regardless of institution type. After this reclassification, students were grouped into four categories: CTeSP, bachelor’s degree, master’s degree, and doctorate. The Kruskal–Wallis test indicated no statistically significant differences in visual knowledge scores among the groups ($\chi^2(3) = 2.274, p = 0.518$). These results suggest that the academic degrees that participants were studying for do not significantly influence students’ performance in correctly identifying chemical hazard symbols. We also applied the same nonparametric test to assess whether visual knowledge levels differed by academic year. The analysis included the first five years of the academic course, with the sixth year being excluded because it had no participants.

The results indicated no statistically significant differences between the groups ($\chi^2(4) = 4.246, p = 0.374$). Nevertheless, an upward trend was observed in the average scores between the 1st (128.69), 2nd (143.05), and 3rd years (154.24), with a slight decrease in the 4th year (146.50) and stable values in the 5th year (150.67). However, the latter group consisted of only three participants. These results suggest that although there is a slight progression in performance during the first years of training, interannual variation is not statistically significant, which may indicate that visual knowledge of chemical hazard symbols is not systematically reinforced throughout the academic course.

3.3. Attitudes Toward Laboratory Chemical Safety—Factorial Structure and Internal Consistency

This section of the questionnaire aimed to assess students’ attitudes toward chemical safety in the laboratory environment. It consisted of four items rated on a five-point Likert scale ranging from “Strongly disagree” to “Strongly agree”. To explore the latent structure of this section, an Exploratory Factor Analysis (EFA) was conducted using Principal Component Analysis (PCA) as the extraction method. KMO (Kaiser–Meyer–Olkin) Measure and Bartlett’s Test of Sphericity determine if the data is suitable for structure detection (factor analysis/PCA). The Kaiser–Meyer–Olkin (KMO) measure was 0.644, indicating acceptable sampling adequacy. Bartlett’s test of sphericity was statistically significant ($\chi^2(6) = 51.038, p < 0.001$), confirming that the variables are sufficiently correlated. The total variance explained is presented in Table 3.

Table 3. Total variance explained by the principal component analysis of the attitude items.

Component	Total Variance Explained					
	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	1.562	39.054	39.054	1.562	39.054	39.054
2	0.876	21.903	60.957			
3	0.803	20.083	81.040			
4	0.758	18.960	100.000			

Extraction Method: Principal Component Analysis (PCA).

The results indicated the presence of a single factor with an eigenvalue of 1.562, explaining 39.05% of the total variance. The remaining components presented eigenvalues below 1 and were therefore excluded from the final solution according to Kaiser’s criterion. Inspection of the scree plot further supported retaining a single factor. The factor loadings (λ) and their corresponding squared loadings (λ^2) for all components are presented in Table 4.

Table 4. Standardized factor loadings (λ) and squared loadings (λ^2).

Component	λ	λ^2
1	0.583	0.340
2	0.671	0.450
3	0.635	0.403
4	0.607	0.369

All items presented factor loadings greater than 0.50, supporting acceptable factorial validity. Additionally, all λ^2 values were ≥ 0.25 , indicating adequate individual-item reliability. The unifactorial structure and satisfactory factor loadings support the construct's interpretability.

The internal consistency of the scale was assessed using Cronbach's alpha coefficient. It obtained a value of $\alpha = 0.434$, indicating low reliability. This value is below the generally accepted minimum threshold of 0.70 for satisfactory internal consistency [8].

The low Cronbach's alpha may suggest that the items are not strongly correlated or do not fully capture a single underlying construct, possibly reflecting limitations in item formulation, conceptual heterogeneity, or differences in participants' interpretations. However, it is important to note that Cronbach's alpha is sensitive to the number of items on a scale, and lower values are commonly observed in short exploratory instruments. In the present case, the scale comprised only four items, which may contribute to an underestimation of internal consistency. For this reason, the interpretation of the scale did not rely solely on the alpha coefficient. Greater emphasis was placed on the factorial structure and theoretical coherence of the items, as all items loaded on the same component with acceptable factor loadings, supporting their conceptual alignment within the construct of attitudes toward laboratory chemical safety. It should also be noted that Cronbach's alpha is sensitive to the number of items on a scale, and lower values are commonly observed in exploratory studies using short instruments, particularly when the construct assessed is conceptually broad.

3.4. Self-Reported Practices Related to Chemical Laboratory Safety

Section 4 of the questionnaire comprises three independent items assessing safety behaviors adopted by students in a laboratory environment: reading SDS (Q19), use of PPE (Q20), and adequate ventilation of workspaces (Q21). Although these items do not constitute a formal psychometric scale, they can be analyzed as specific behavioral indicators, enabling the exploration of patterns of safe practices in higher education.

To explore associations between reported safety practices, Spearman's correlation coefficients were calculated for the three instrument items. The results revealed positive and statistically significant correlations between all pairs of variables: between item Q19 and item Q20 there was a weak correlation ($\rho = 0.198$, $p = 0.001$); between item Q19 and Q21 a weak to moderate correlation was observed ($\rho = 0.211$, $p < 0.001$); the strongest correlation was between Q20 and Q21, with a moderate association ($\rho = 0.266$, $p < 0.001$).

These results suggest that the three items are related but measure distinct dimensions, given that the correlation coefficients do not exceed the threshold for redundancy (>0.80). The positive correlations indicate that as the value of one item increases, the others also tend to increase, though the intensity of this association varies.

To assess the influence of self-reported knowledge levels on perceptions of chemical risk in the laboratory, the Kruskal–Wallis test was applied to items Q19 to Q21 of the questionnaire. The continuous variable Knowledge Score was categorized into three groups—low, medium, and high knowledge—by dividing it into thirds, allowing for comparison of responses to items across different levels of knowledge.

The results, shown in Table 5, indicate that, in item Q19 there were no statistically significant differences between the groups ($\chi^2(2) = 0.236, p = 0.889$). The mean scores were relatively close, suggesting a homogenous perception among participants, regardless of their level of knowledge. Similarly, item Q20 showed no significant differences between the groups ($\chi^2(2) = 2.258, p = 0.323$), although there was a slight tendency toward higher mean ranks in the groups with greater knowledge. However, this tendency did not reach statistical significance. In item Q21, a statistically significant difference was identified between the knowledge groups ($\chi^2(2) = 8.765, p = 0.012$). The average rank was substantially higher in the group with greater knowledge, indicating that participants with higher levels of knowledge assign higher ratings to this item.

In interpretative terms, these results suggest that although the overall perception of the risks addressed in items Q19 and Q20 appears relatively consistent across students, item Q21 is more sensitive to knowledge levels, possibly reflecting a more technical or cognitive dimension of chemical risk. This difference may indicate that some aspects of risk perception (particularly those related to more specific knowledge) are influenced by prior literacy in laboratory and chemical safety.

Table 5. Kruskal–Wallis Test by Knowledge Group.

Item	Mean Rank Low	Mean Rank Medium	Mean Rank High	H (Kruskal–Wallis)	p-Value
Q19	132.50	140.22	143.46	0.236	0.889
Q20	139.44	130.21	145.63	2.258	0.323
Q21	119.67	118.47	149.30	8.765	0.012 *

* $p < 0.05$.

To analyze whether prior training in laboratory safety influences the adoption of safety practices, the nonparametric Mann–Whitney U test was applied to all three items of Section 4, since the independent variable (training: yes/no) is binary and the dependent variable (safety practices) is ordinal with three categories (never, rarely, always).

The results revealed that in item Q19, no statistically significant differences were observed between the groups ($U = 5818.500, Z = -0.938, p = 0.348$), suggesting that prior training does not significantly influence behaviors related to the specific practice of reading SDSs. In item Q20, there was a statistically significant difference between groups ($U = 5080.000, Z = -2.694, p = 0.007$), indicating that students with prior training tend to use PPE more frequently. Item Q21 also showed a significant difference, although less pronounced ($U = 5334.500, Z = -1.994, p = 0.046$), indicating an association between prior training and greater adherence to the practice in question.

These results suggest that prior training in laboratory safety can positively affect certain safety practices, underscoring the importance of systematically integrating this content into academic curricula. However, not all practices appear to be equally influenced, which may indicate differences in the transferability or practical applicability of the safety protocols explained.

3.5. Students' Knowledge and Use of Emergency Equipment

Students generally reported frequent adherence to safe laboratory practices, particularly adequate ventilation (53.2% “always”) and the use of personal protective equipment (65.8% “always”). However, consultation of Safety Data Sheets showed lower adherence, with a substantial proportion reporting that they consulted them only occasionally or never. Waste disposal practices were largely appropriate, with most students indicating that they disposed of waste in designated containers.

Regarding emergency preparedness, most participants reported knowing the location and use of only some emergency equipment, suggesting partial familiarity with

laboratory safety infrastructure. Responses to emergency scenarios indicated generally adequate first-aid knowledge, particularly for skin and eye contact with corrosive substances. Nevertheless, notable gaps were observed in spill-response procedures, with a proportion of students indicating uncertainty or inappropriate actions.

Overall, these findings indicate satisfactory baseline preparedness but highlight specific areas requiring reinforcement, particularly routine consultation of safety documentation and practical emergency-response training. Detailed response distributions are provided in Appendix B (Figures A1–A7).

4. Discussion

4.1. Knowledge of Chemical Hazard Symbols

This study contributes to the growing body of research on chemical safety in higher education laboratories by providing empirical evidence on students' knowledge, attitudes, and self-reported practices within the Portuguese academic context. Overall, the findings indicate that students generally demonstrate adequate levels of declarative knowledge, particularly regarding the recognition of chemical hazard pictograms.

The relatively high mean score obtained for GHS pictogram recognition is consistent with previous studies reporting satisfactory levels of visual hazard literacy among tertiary students. Walters et al. [9] similarly observed high levels of awareness among chemistry and biology students, while also highlighting persistent deficiencies in hazard identification and emergency response. Comparable results were reported by Al-Zyoud et al. [5], who found fair to good familiarity with chemical warning signs among engineering students, despite notable variability across hazard categories.

Taken together, these findings suggest that familiarity with hazard symbols may largely result from repeated exposure during laboratory activities rather than from systematic safety training. Importantly, the absence of statistically significant differences in knowledge scores across academic cycles and years observed in the present study suggests that chemical safety knowledge may not be progressively reinforced throughout students' academic trajectories. This observation aligns with bibliometric evidence indicating that laboratory safety education in universities often remains fragmented and insufficiently integrated across curricula [4]. Similar concerns were raised by Wu et al. [10], who found that academic major and prior training experience—rather than academic seniority alone—were the strongest predictors of laboratory safety awareness.

4.2. Attitudes Toward Chemical Safety

The analysis of the attitude items revealed a unidimensional structure; however, the internal consistency of the scale was relatively low. This result suggests that attitudes toward chemical safety may be heterogeneous and influenced by contextual factors rather than representing a strongly cohesive latent construct.

Previous research indicates that safety attitudes in laboratory environments are shaped by multiple influences, including risk perception, perceived importance of safety procedures, and the institutional context in which laboratory activities occur. Abdullah and Aziz [11], drawing on the Theory of Planned Behavior, demonstrated that safety commitment mediates the relationship between knowledge, motivation, and safety behavior, highlighting the importance of attitudinal and normative components in shaping compliance.

In this context, the relatively low reliability observed in the attitude scale may reflect the situational nature of students' perceptions of laboratory safety. Rather than representing stable attitudes, students' responses may be influenced by the specific laboratory

environments in which they work, including supervisory practices, peer behaviors, and perceived institutional expectations.

4.3. *Self-Reported Safety Practices*

The results related to laboratory safety practices reveal a mixed pattern. On the one hand, several safety behaviors appear to be widely adopted by students, particularly the use of personal protective equipment (PPE) and adequate ventilation of laboratory workspaces. These practices are highly visible and are often reinforced by instructors and laboratory supervisors during experimental activities.

On the other hand, behaviors that require more proactive engagement with safety information—such as consulting Safety Data Sheets (SDS) before using unfamiliar chemicals—were reported less consistently. This finding suggests that practices involving information-seeking behavior may not be as systematically internalized as more observable safety procedures.

Such discrepancies between knowledge and practice have also been documented among professional laboratory researchers. Papadopoli et al. [12], for example, reported that acceptable levels of knowledge and risk awareness may coexist with inconsistent adherence to safety procedures. Similarly, Al-Zyoud et al. [5] observed that students may demonstrate reasonable levels of knowledge and practice while still exhibiting suboptimal safety attitudes.

4.4. *The Knowledge–Behavior Gap*

One of the central themes emerging from the present results is the disconnect between knowledge and behavior. Although students demonstrated relatively high levels of familiarity with chemical hazards and reported frequent adoption of certain safety practices, other behaviors were less consistently implemented.

This pattern reflects a well-documented phenomenon in safety research, where awareness of risks does not necessarily translate into consistent behavioral compliance. Walters et al. [9] also reported weak associations between awareness and safety practices, suggesting that knowledge alone is not sufficient to ensure safe laboratory conduct.

Evidence from intervention-based research further supports this interpretation. Studies evaluating laboratory safety training programs have shown that structured educational interventions can significantly improve students' knowledge, risk perception, and safety attitudes, yet produce only limited short-term changes in actual safety behavior [13]. This pattern suggests that behavioral adoption depends not only on individual awareness but also on reinforcement mechanisms, social norms, and the broader organizational context in which laboratory activities occur. The limited influence of prior training on some of the practices assessed in this study—such as routine consultation of SDS—may reflect differences in how safety procedures are communicated and reinforced in daily laboratory work. From a behavioral perspective, this discrepancy may also be interpreted through frameworks such as the Theory of Planned Behavior, which proposes that knowledge alone is insufficient to determine behavior unless accompanied by favorable attitudes, perceived behavioral control, and supportive social norms. This perspective may help explain why students with adequate knowledge do not always demonstrate consistent safety practices.

4.5. *Role of Institutional Context and Safety Climate*

The interpretation of the present findings can also be informed by research on safety climate in academic laboratories. Salazar-Escoboza et al. [14] demonstrated that students' safety behaviors are strongly influenced by their perceptions of institutional commitment to safety, leadership engagement, and the example set by professors and laboratory staff.

Their findings suggest that students tend to internalize safety practices primarily through observation and practical examples rather than through formal instruction alone.

Similar patterns have been identified among professional researchers. Schröder et al. [15] found that safety compliance in laboratory environments was strongly associated with risk perception and with the active involvement of laboratory supervisors or principal investigators. These results highlight the importance of organizational safety culture in shaping everyday laboratory practices.

The present results are consistent with this broader perspective. In particular, the finding that prior safety training was associated with increased adherence to PPE use and ventilation practices—but not with less visible behaviors such as SDS consultation—may reflect differences in how strongly specific practices are reinforced within laboratory environments.

4.6. Implications for Laboratory Safety Education

The limited knowledge observed about the location and use of emergency equipment, as well as the uncertainty reported in spill-response scenarios, raises additional concerns about students' practical preparedness. Although most participants correctly identified appropriate first-aid responses to chemical exposure, a non-negligible proportion reported unsafe or inadequate actions.

Similar gaps have been documented in other educational contexts, reinforcing calls for more practical and experiential approaches to safety training. Studies have highlighted the importance of hands-on training, simulation exercises, and scenario-based learning as essential complements to theoretical instruction in laboratory safety education [16,17].

At a broader level, the present findings are consistent with research emphasizing the predominance of human and organizational factors in laboratory risk. Advanced risk-assessment approaches, such as the Bayesian network models proposed by Zhao et al. [18], consistently identify human behavior and insufficient training as key contributors to unsafe laboratory conditions. These results support earlier arguments by Olewski and Snakard [19], who emphasized that academic laboratories should not be assumed to pose lower risks than industrial environments, particularly when safety management systems and leadership engagement are insufficient.

Taken together, these findings suggest that improving chemical safety in higher education laboratories requires strategies that extend beyond knowledge transmission alone. Safety should instead be understood as a dynamic and socially mediated process shaped by institutional culture, safety climate, and the alignment between formal instruction and observed laboratory practices. Similar conclusions were reached in broader research on higher education safety, which highlights the importance of institutional context and safety-related attitudes in shaping preparedness and compliance behaviors among students [20].

Consistent with previous studies [5,9,14], the present results suggest that effective safety education in laboratory environments should integrate theoretical instruction with continuous reinforcement of safety practices, practical training opportunities, and active engagement of instructors and laboratory supervisors. Although the findings should be interpreted as exploratory evidence, they contribute to a better understanding of how students perceive and adopt chemical safety practices in academic laboratory settings.

4.7. Limitations of the Study

Several limitations should be considered when interpreting the findings of this study.

First, the study relied on a convenience sample of students enrolled in laboratory-based courses in Portuguese higher education institutions. Although this approach allowed the collection of responses from a relatively large number of participants, the non-

probabilistic sampling strategy limits the generalizability of the results. In addition, some subgroups within the sample were unevenly represented, particularly students in later academic years, which restricts the robustness of subgroup comparisons.

Second, the assessment of laboratory safety practices was based on self-reported behaviors. Self-report measures may be affected by social desirability bias, especially in safety-related contexts where participants may feel inclined to report behaviors that align with expected safety standards. Consequently, the reported frequency of certain practices—such as the use of personal protective equipment—may overestimate actual behaviors observed in laboratory settings.

Third, the psychometric properties of the Attitudes Toward Laboratory Chemical Safety subscale should be interpreted with caution. The internal consistency of this scale was relatively low, suggesting that the four items may not represent a strongly cohesive latent construct. Although exploratory dimensionality analysis indicated a unidimensional structure with acceptable factor loadings, the explained variance and reliability indices provide only modest support for the construct. Therefore, the attitude findings should be interpreted as exploratory indicators rather than definitive measures of laboratory safety attitudes. Future studies should consider expanding and refining the item pool and conducting more comprehensive psychometric validation procedures in larger and more diverse samples. Finally, the study's cross-sectional design does not allow causal relationships to be established among knowledge, attitudes, and safety practices. The observed associations should therefore be interpreted as indicative patterns rather than evidence of causal mechanisms.

Future research could address these limitations by employing longitudinal designs, incorporating observational assessments of laboratory behavior, further validating measurement instruments adapted for different educational contexts, and applying multivariate analytical approaches to explore better the relationships among knowledge, attitudes, and safety behaviors.

5. Conclusions

Safety in educational laboratories is a critical component of academic practice, particularly in disciplines where laboratory activities are central to professional training. The results of this study provide exploratory insights into higher education students' knowledge, attitudes, and self-reported practices related to chemical safety in laboratory environments. Overall, the findings suggest that students generally demonstrate satisfactory levels of chemical safety knowledge. However, gaps remain between knowledge, attitudes, and the consistent adoption of safe laboratory behaviors. These results should therefore be interpreted as exploratory evidence regarding students' knowledge and self-reported practices rather than as definitive conclusions about institutional safety culture or the effectiveness of specific curricular approaches. The findings also indicate that strengthening laboratory safety among students may require educational strategies that extend beyond theoretical instruction. Integrating chemical safety education across curricula, reinforcing safety procedures through continuous training, and promoting practical learning activities—such as simulations and emergency response exercises—may help improve students' preparedness and risk awareness. In addition, the results suggest that safety behaviors may be influenced not only by individual knowledge but also by contextual factors within the laboratory environment. This highlights the potential importance of both bottom-up educational initiatives and broader institutional engagement in promoting safe laboratory practices. Although exploratory in nature, this study contributes to a better understanding of chemical safety awareness and behaviors among higher education students. One of its main findings is that satisfactory knowledge levels may coexist with inconsistencies in self-reported safety practices, reinforcing the importance of

addressing laboratory safety through approaches that extend beyond knowledge transmission alone. Practical strategies such as repeated safety training, emergency simulations, and active involvement of faculty and laboratory supervisors may help strengthen safety preparedness and support the development of safer laboratory environments.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in this study.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

CTeSP	Short Cycle Higher Technical Professional Programs
EFA	Exploratory Factor Analysis
GDPR	General Data Protection Regulation
GHS	Globally Harmonized System
KMO	Kaiser–Meyer–Olkin
PPE	Personal Protective Equipment
SDS	Safety Data Sheet

Appendix A

The questionnaire presented below corresponds to the Portuguese version adapted for this study. The original English version of the instrument was developed by Al-Zyoud et al. [5] and can be consulted in the original publication.

Versão Portuguesa do Questionário de Segurança Química em Laboratório (LCSQ-PT)

Declaro que:

Todas as informações prestadas no presente questionário são verdadeiras.







Tomei conhecimento da finalidade, prazo de tratamento e direitos ao abrigo do RPGD que assistem aos dados pessoais solicitados e por mim facultados.

Secção 1: Informação sociodemográfica

1. Género:
 - a. Feminino
 - b. Masculino
 - c. Outro
 - d. Prefiro não responder
2. Faixa etária
 - a. 18–20

- b. 21–25
 - c. 26–29
 - d. Mais de 30
3. Qual o ciclo de estudos em que se encontra inscrito?
 - a. Licenciatura
 - b. Mestrado
 - c. CTeSP
 - d. Doutoramento
 4. Em que ano se encontra inscrito?
 - a. 1º ano
 - b. 2º ano
 - c. 3º ano
 - d. 4º ano
 5. Alguma vez teve formação relativa a procedimentos de segurança em laboratório?
 - a. Sim
 - b. Não

Secção 2: Familiarização e conhecimento de Pictogramas de Perigo

Questão	Pictograma	Propriedade Química	Propriedade Química
11		Não sei o que este símbolo representa	
12		Não sei o que este símbolo representa	
13		Não sei o que este símbolo representa	A. Perigoso para a saúde B. Irritante C. Tóxico D. Explosivo E. Corrosivo
14		Não sei o que este símbolo representa	F. Inflamável G. Comburente H. Gás sob pressão I. Perigoso para o ambiente
15		Não sei o que este símbolo representa	
16		Não sei o que este símbolo representa	

17



Não sei o que este símbolo representa

18



Não sei o que este símbolo representa

19



Não sei o que este símbolo representa

Secção 3: Atitudes perante Segurança Química em Laboratório

Por favor, responda às seguintes questões utilizando a escala:

Concordo Totalmente	Concordo	Neutro	Discordo	Discordo Totalmente
---------------------	----------	--------	----------	---------------------

20. Equipamentos de Proteção Individual (EPI) são obrigatórios apenas quando se manuseiam produtos químicos em laboratório

Concordo Totalmente	Concordo	Neutro	Discordo	Discordo Totalmente
---------------------	----------	--------	----------	---------------------

21. É sempre seguro descartar resíduos químicos na rede de saneamento pública quando os diluimos em grandes quantidades de água

Concordo Totalmente	Concordo	Neutro	Discordo	Discordo Totalmente
---------------------	----------	--------	----------	---------------------

22. Antes de um procedimento químico, não é necessário repetir as regras de segurança

Concordo Totalmente	Concordo	Neutro	Discordo	Discordo Totalmente
---------------------	----------	--------	----------	---------------------

23. Derrames de produtos químicos em pequenas quantidades não é perigoso, independentemente do tipo de produto

Concordo Totalmente	Concordo	Neutro	Discordo	Discordo Totalmente
---------------------	----------	--------	----------	---------------------

Secção 4: Práticas de Segurança Química em Laboratório

Por favor, responda às seguintes questões utilizando a escala:

Nunca	Frequentemente	Sempre
-------	----------------	--------

24. Antes de utilizar um novo produto químico, com que frequência lê as Fichas Dados de Segurança (FDS)?

Nunca	Frequentemente	Sempre
-------	----------------	--------

25. Com que frequência utilizada apropriadamente os EPI's (incluindo bata, luvas, óculos de proteção), quando trabalha em laboratório?

Nunca	Frequentemente	Sempre
-------	----------------	--------

26. Com que frequência usa ventila apropriadamente os espaços de trabalho em laboratório (EX: utilização correta das hottes)?

Nunca	Frequentemente	Sempre
-------	----------------	--------

Para a questão seguinte, escolha a resposta mais apropriada:

27. Quando o procedimento experimental estiver terminado, como é que normalmente descarta os resíduos?
- Para o saneamento, diluídos com água
 - Colocando-os nos jerricans adequados
 - Colocando-os nos recipientes originais do produto
 - Outro. Por favor, especifique:

Secção 5: Equipamentos de Emergência e Procedimentos

28. Sabe onde se encontram localizados os equipamentos de emergência (lava olhos, chuveiro, extintores, mantas ignífugas, kit de primeiros socorros)?
- Sim, sei onde estão localizados todos os equipamentos
 - Sei onde estão localizados alguns dos equipamentos
 - Não sei onde estão localizados os equipamentos
29. Sabe como utilizar os equipamentos de emergência (lava olhos, chuveiro, extintores, mantas ignífugas, kit de primeiros socorros)?
- Sim, sei utilizar todos os equipamentos de emergência
 - Sei como utilizar apenas alguns dos equipamentos (Coloque um visto ao lado do equipamento que sabe utilizar)

Lava olhos	Chuveiro	Extintor	Manta ignífuga	Kit primeiros socorros
------------	----------	----------	----------------	------------------------

- Não sei utilizar nenhum equipamento de emergência
30. Quando ocorre um derrame de um ácido/base na bancada de trabalho ou no chão, enquanto elabora um procedimento experimental, como reage?
- Limpar o derrame com um pano seco e lavá-lo no lavatório
 - Utilizar um neutralizante no químico derramado (Kit Controlo de Derrames)
 - Não sei como proceder neste caso
 - Outro. Por favor, especifique
31. Quando um ácido/base entra em contacto com a pele, qual é a primeira coisa que deve fazer?
- Limpar com uma toalha
 - Colocar o local de contacto debaixo de água a correr
 - Neutralizá-lo com outro químico
 - Outro. Por favor, especifique _____
32. Quando um ácido/base entra em contacto com os olhos, qual a primeira coisa que deve fazer?
- Limpar com uma toalha
 - Neutraliza-lo com outro químico
 - Limpar imediatamente os olhos com água
 - Procurar ajuda médica imediatamente
 - Outro. Por favor, especifique _____

Appendix B

Detailed Response Distributions for Emergency Equipment and Safety Practices

In this section, students were asked about their practical knowledge regarding the use of emergency equipment in laboratories.

Questions such as how often they adopt certain safety practices in the laboratory, namely adequate ventilation of the space, correct use of PPE, and consultation of SDS before handling new chemicals, were made. The results, shown in Figure A1, show that most students report adopting these practices regularly although there are variations in the behavior analyzed.

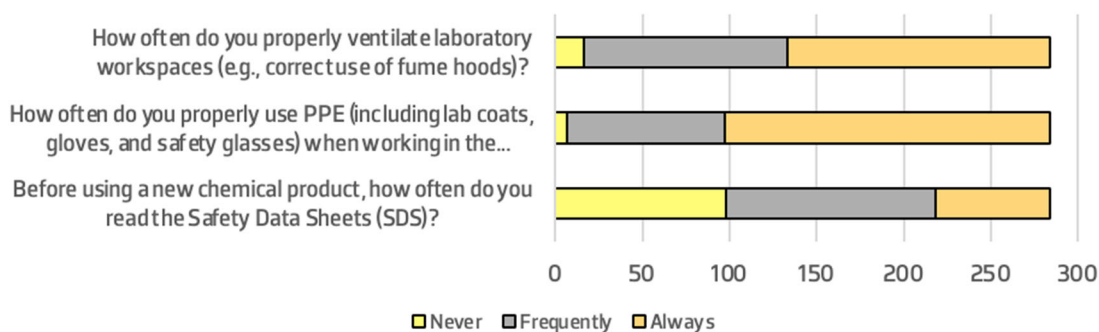


Figure A1. Self-reported frequency of chemical safety practices among higher education students in laboratory settings.

For the first question, “adequate ventilation in laboratory spaces” (e.g., correct use of fume hoods), most participants indicated that they “always” ($n = 151$) perform this practice, with a smaller proportion responding “frequently” ($n = 117$) and a very small fraction indicating that they “never” ($n = 16$) do so.

Regarding the use of PPE (gowns, gloves, and protective eyewear), more than a half of the students indicated that they “always” ($n = 187$) use PPE, with a significant portion selecting “frequently” ($n = 90$) and a minority selecting “never” ($n = 7$).

Consultation of SDS before using a new chemical product, this practice showed greater variability, with a significant number of students reporting that they only do so “frequently” ($n = 120$) or “never” ($n = 98$), highlighting a potential gap in access to or appreciation of this critical source of information.

These results suggest that, although safety behaviors are well established in some areas, systematic consultation of SDSs remains a less established practice, which may justify more specific awareness-raising interventions in this area.

In order to understand students’ behavior regarding the disposal of chemical waste after completing laboratory procedures, a question was included about the practice usually adopted in this context.

The results, shown in Figure A2, clearly show that the overwhelming majority of participants say they place waste in appropriate containers ($n = 279$), in accordance with hazardous laboratory waste management standards.

When the experimental procedure is complete, how do you normally dispose of the waste?

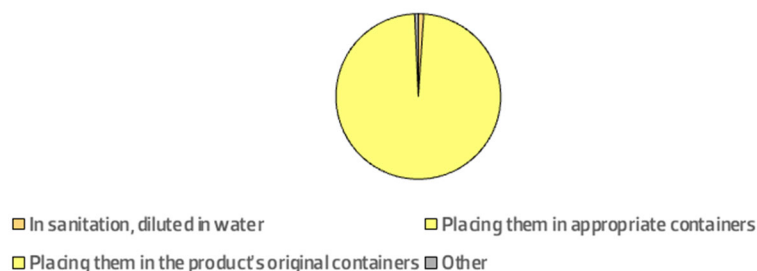


Figure A2. Self-reported waste disposal practices among students following experimental procedures.

The remaining options—namely disposal in the sewage system after dilution in water ($n = 3$), placing the waste in the original product containers ($n = 0$), or other practices ($n = 2$)—were mentioned only rarely, with no more than a symbolic number of responses.

This trend is encouraging, as it demonstrated environmental awareness and a basic understanding of the rules for separating and storing chemical waste. Nevertheless, it is important to ensure that this practice is properly consolidated through ongoing practical training and institutional reinforcement, to prevent possible errors or inconsistent behavior in real laboratory contexts.

The students' level of knowledge regarding the location of emergency equipment in the laboratory was also assessed, including eye wash stations, emergency showers, fire extinguishers, fire blankets and first aid kits.

As shown in Figure A3, most participants stated that they know where only some of the emergency equipment is located ($n = 161$), revealing partial knowledge about the organization and signage of the available resources.

Do you know where the emergency equipment is located (eye wash station, shower, fire extinguishers, fire blankets, first aid kit)?



Figure A3. Students' awareness of the location of emergency equipment in laboratory settings.

A smaller proportion of students indicated that they knew the location of all equipment ($n = 114$), demonstrating a higher level of familiarity with the laboratory spaces and its safety resources.

On the other hand, a small number of respondents revealed that they did not know where any of the equipment was located ($n = 9$), which may indicate a lack of practical training, insufficient signage, or a lack of clear instructions at the beginning of laboratory activities.

This pattern of responses highlights the importance of strengthening visual communication, adequate signage, and initial training on the location and handling of emergency equipment, promoting a rapid and effective response in the event of an incident.

In addition to location, students were also asked about their level of practical knowledge regarding the use of laboratory emergency equipment. As shown in Figure A4, most participants indicated that they know how to use only some of this equipment ($n = 124$), revealing partial knowledge that is possibly limited to those items with which they have more frequent contact.

Do you know how to use emergency equipment (eye wash, shower, fire extinguishers, fire blankets, first aid kit)?

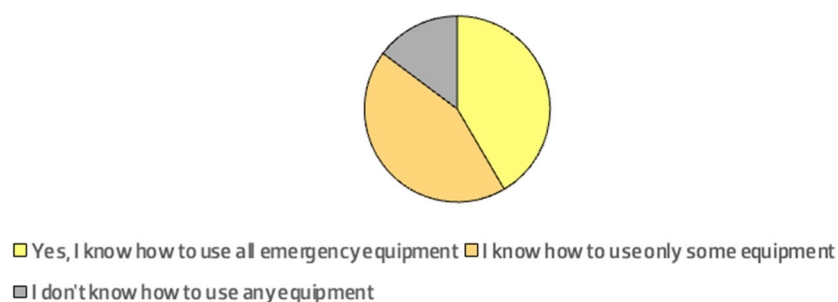


Figure A4. Self-reported ability to use emergency laboratory equipment among higher education students.

A smaller proportion said they were proficient in the use of all emergency equipment ($n = 118$), which may reflect more intensive laboratory experience or additional training in academic or professional context. On the other hand, a significant group revealed that they did not know how to use any equipment ($n = 42$), raising relevant concerns in terms of practical preparedness to deal with emergency situations.

These data reinforce the need to focus not only on theoretical awareness, but also on regular practical training on the correct handling of emergency equipment, ensuring that all students have the ability to act effectively in the event of an accident.

How to proceed in the event of an acid or base spill on a workbench or on the laboratory floor during an experimental procedure was also one of the questions posed to participants.

According to the data presented in Figure A5, most students indicated that they would use a specific neutralizer (Spill Control Kit) ($n = 191$), which is the most appropriate and safest response according to good laboratory practices.

When an acid/base spill occurs on the workbench or floor while conducting an experimental procedure, how do you react?

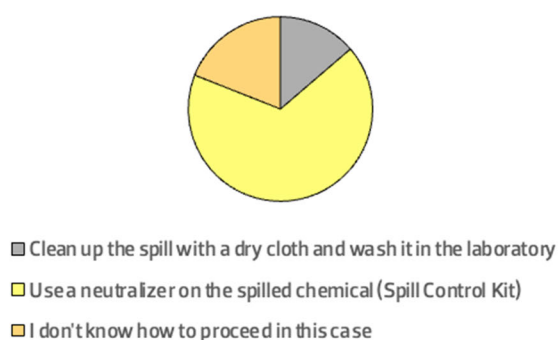


Figure A5. Students' self-reported responses to acid/base spills during laboratory procedures.

A smaller percentage said they would clean it up with dry cloth, followed by washing in the laboratory itself ($n = 39$), which can be considered an inappropriate procedure, especially when it involves corrosive or toxic substances. Finally, a significant proportion of students ($n = 54$) admitted that they did not know how to respond to this type of occurrence, highlighting an important gap in practical training in chemical safety.

This result reveals that, although there is a knowledge base on the use of neutralization kits, the lack of comprehensive and systematic training on chemical emergency response still affects a portion of students. The inclusion of practical simulations, training on spill kits, and accident response protocols may be essential to consolidate a more robust safety culture.

The students' perception of the immediate procedure to be adopted in case of contact of acid or base with the skin was also evaluated.

According to the data presented in Figure A6, the response most selected by the participants was to immediately place the contact area under running water ($n = 234$), which is in accordance with the recommended first aid protocols for this type of accident. A small number of students indicated incorrect alternatives, such as cleaning with a dry towel ($n = 16$) or attempting to neutralize with another chemical ($n = 33$), which may represent an increased risk of aggravating the injury or causing an unwanted chemical reaction. The "other" option was selected by a small fraction ($n = 1$), which may include non-standard, unclear, or possibly correct answers that do not fit into the categories provided.

When an acid/base comes into contact with your skin, what is the first thing you should do?

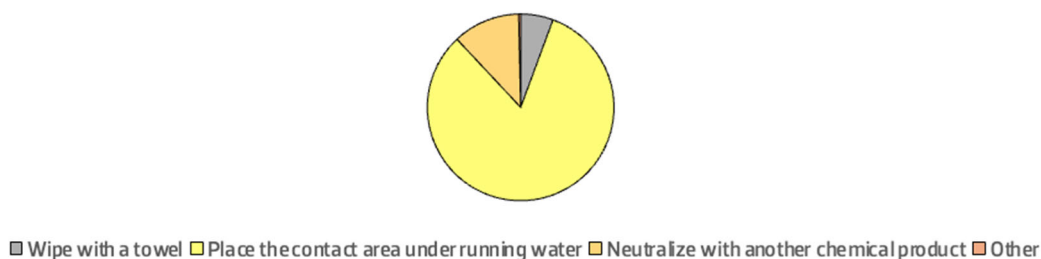


Figure A6. Students' responses to chemical contact with skin involving acids or bases.

These results are generally positive, as they show that most students have adequate knowledge about the first aid measures to take in case of skin contact with corrosive products. Nevertheless, it is important to ensure that this knowledge is universal among students and that is associated with practice and training in simulated contexts, in order to promote quick and effective responses in real situations.

In a more serious situation, participants were asked about the immediate action to take in case of accidental contact of an acid or base with the eyes, one of the most critical scenarios in a laboratory environment.

As illustrated in Figure A7, the overwhelming majority of students correctly identified immediate washing of the eyes with running water as the most appropriate procedure ($n = 227$). This response is in line with international first aid protocols for cases of eye exposure to corrosive chemicals.

Despite this encouraging result, a fraction of students selected incorrect or potentially dangerous responses, such as using towel to clean the eye area ($n = 3$) or attempting to neutralize the chemical with another product ($n = 2$)—practices that should be avoided at all costs. Some responses indicate seeking immediate medical help ($n = 52$), which,

although recommended at a later stage, does not replace the priority and urgent action of continuous irrigation with water.

When an acid/base comes into contact with your eyes, what is the first thing you should do?

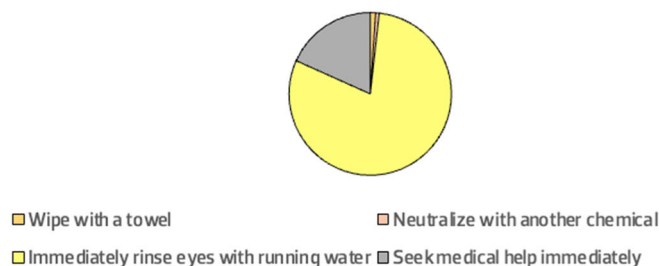


Figure A7. Students' responses to accidental acid/base contact with the eyes during laboratory activity.

The data therefore reveal a high level of knowledge about the first aid measures to be taken in situations of eye risk, which is essential to minimize permanent injury. However, the existence of incorrect answers still present in the group indicates that chemical safety training should continue to reinforce the role of eye wash stations and the appropriate conduct in the event of this type of accident.

Overall, the results show that higher education students demonstrate satisfactory levels of knowledge and practices related to laboratory safety, particularly regarding the use of emergency equipment, response to critical situations, and compliance with preventive measures. Most participants were able to correctly identify the immediate procedures in case of contact with acids/bases on the skin or in the eyes and indicated that they knew the location (albeit partial) and use of some of the most common emergency equipment, such as eye wash stations, safety showers, and first aid kits.

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