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SAFETY CLIMATE AND SAFETY CULTURE OF CHEMICAL ENGINEERING LABORATORIES OF UNIVERSITI TEKNOLOGI MALAYSIA

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ABSTRACT

Laboratory safety could pose a high risk due to the presence of hazards, physical, electrical, chemical, etc. Such conditions expose students or university staff to potential accidents in laboratories. The lack of safety climate and safety culture among university students is one of the main contributing factors to laboratory accidents. Therefore, this research aims to assess and improve the safety climate and safety culture among undergraduate students in the Faculty of Chemical and Energy Engineering (FCEE) at Universiti Teknologi Malaysia (UTM), specifically within the Separation Process and Fluid Mechanics laboratories. The assessment will focus mainly on individuals actively engaged in laboratory work -- safety attitude, awareness, behaviours, and perceptions. A set of questionnaires is a tool to collect data on these variables, i.e. safety attitude, awareness, behaviours, and perceptions. The questionnaire was used to collect student data to assess their safety climate and safety culture in the academic laboratory setting. The questionnaire consists of socio-demographic, safety attitude, safety awareness, safety behaviour, and safety perception sections. The data was analyzed by using Kruskal Wallis test, Mann Whitney U-test, and Spearman Correlation. The study found that significant differences in the safety culture of undergraduate chemical engineering students in academic laboratories were influenced by factors such as age, years of study, laboratory experience, and participation in safety training, while safety climate was significantly impacted by the length of time spent in the lab and participation in safety training.

Keywords: Safety Culture, Safety Climate, Laboratory Safety, University, Undergraduate.

1.0 INTRODUCTION

College and university laboratories serve as an important part in regular-class lessons and academic research, with the purpose of developing potential and probing scientific unknowns [1]. However, during laboratory experiments for educational purposes and research, professors, lecturers, and students are dealing with machinery, processes, and substances that have intrinsic risks such as high temperature, high pressure, flammability, and toxicity. The presence of these dangers poses significant risks and may result in catastrophic accidents. Laboratory incidents may occur as a result of insufficient risk assessment and prevention, as well as a diversion from experimental methods. Laboratory safety has emerged as a significant concern in colleges and universities, because of a rise in incidents in laboratories and greater awareness. However, the recurrence of incidents over an extended period implies that a more structured approach to identifying hazards is necessary [2].

In the United States, the management of hazard recognition in laboratories is typically carried out in accordance with either the U.S. OSHA Laboratory Standard or the Hazard Communication Standard. Both approaches prioritise the communication of hazard information through the utilisation of Safety Data Sheets

(SDS) and product labels. The Laboratory Standard assigns significant responsibility for hazard control to individuals who possess technical qualifications and work in chemical laboratories. Chemical usage varies significantly between academic laboratories and industrial settings due to their distinct objectives, available resources, and safety approaches [3]. In academic laboratories, chemical selection is tailored to suit specific research needs and budget limitations. As a result, researchers may opt for smaller quantities or lower purity grades of chemicals to align with their experimental requirements. In contrast, industries prioritize the quality and purity of chemicals to ensure consistent and reliable outcomes in their large-scale manufacturing processes [4].

In 2007, the Chemical Abstract Registry contained over 85 million entries, including 28 million chemical and inorganic compounds. Currently, Chemical Abstract Registry contains more than 182 million distinct organic and inorganic chemical compounds. Numerous dangerous compounds are used in a normal laboratory environment for a range of processes. Research conducted by The Center for Disease Control and Prevention (CDC) in United States examined data on emergency department encounters with hazardous substances from nine states as part of lengthy research. There were 57,975 of them accidents between 1999 and 2008, and 4,621 of them led to 15,506 injuries. The chemical sector employed the majority of those who were hurt with 1,753 injuries whereas academic centres unexpectedly came in second place with 1,562 injuries [5].

Accidents that occur in a lab setting might be unfavourable to the institution. Additionally, it leads to users of laboratories experiencing heightened psychological consequences, such as depression and anxiety, as well as reduced efficiency and productivity. Research conducted by Legget in 2012 concluded that results from accident cases often show that the lack of risk assessment or hazard identification was a contributing factor. Therefore, a university laboratory must inculcate safety culture to minimize and avoid accidents and to safeguard the health and safety of undergraduate and postgraduate students.

The risk management of chemical hazards is an essential component in safeguarding the well-being and security of individuals, the surrounding ecosystem, and people in general. The process entails a methodology that encompasses the identification, evaluation, and management of potential risks linked to the handling, storage, and disposal of hazardous chemicals. In order to proficiently handle chemical hazards, it is imperative for organizations to carry out comprehensive risk assessments with the aim of comprehending the potential risks and their corresponding consequences. The implementation of engineering controls, administrative measures, and personal protective equipment (PPE) can effectively mitigate risks and prevent accidents. The implementation of regular training and awareness programs for employees is crucial in fostering the adoption of safe practices and augmenting hazard awareness. Furthermore, the appropriate identification, containment, and manipulation of chemical substances are integral aspects of risk mitigation, guaranteeing the secure and regulated utilization of chemicals.

Understanding risks, assessing hazards, and developing a plan to reduce laboratory accidents would all be helped by an integrated health, safety, and environmental risk assessment [6]. International organisations for occupational safety and health have created guidelines and standards to avoid and mitigate risks in lab settings. A culture of safety, health, and environmental awareness in dealing with laboratory risks and hazards was created via the training of students and lab staff [7]. Even though risk assessment has shown to be an effective method for locating and implementing the right controls to manage risks and hazards, laboratory risk levels might vary depending on the activities, attitude, awareness, behaviour and perception towards safety in laboratory environment. In order to successfully apply controls, the laboratory risk assessment should be conducted for each unique laboratory environment, as well as for each work activity and job [8]. Health, safety, and risk management specialists in chemical laboratories have had difficulties obtaining unbiased and thorough data about risks and hazards. The definition of an evaluating project with a knowledgeable team is necessary for planning a risk assessment. The commencement, or initial stage, in determining the severity of the effect of danger, is hazard prediction and identification.

The investigation of safety issues in regard to university students inside educational institutions from a safety culture viewpoint requires further research to gain insight into these matters. There exists a significant association between accidents that take place in university settings and the safety behaviour, safety attitude, and safety awareness shown by undergraduate and postgraduate students. These characteristics include the fundamental elements of the organisational safety culture. Insufficient study has been conducted about the safety culture among university students in Malaysia. Bena et al. (2016) conducted an analysis of the efficacy of safety culture interventions in Italian schools regarding students' injuries [9]. The research findings indicated an overall decrease in the incidence of indoor injuries after the implementation of these interventions. The study conducted by Walters et al. (2017) investigated the attitudes, knowledge, and practices related to chemical laboratory safety among students in Trinidad [10]. The findings of the study indicated a need for more educational and training initiatives to enhance the overall safety culture within laboratory settings [10]. Hence, fostering and integrating a safety culture among university students is a crucial step toward establishing a laboratory environment that is free from accidents.

2.0 METHODOLOGY

This section presents on methodology to how to assess the safety culture of undergraduate students actively engaged in laboratory works. First and foremost, the problem statement, objectives and hypothesis of the research were outlined. Next, literature review was conducted to get a better understanding of the subject matter as well as to investigate similar issues studied by previous researchers. The first part of the methodology covers the pilot test and reliability test to ensure the questions are valid and relevant to the subject matter. Then, distribution and collection of questionnaires to assess of the safety culture of undergraduate chemical engineering students was carried out. Subsequently, the data obtained from the questionnaire was analysed and discussed in detail in order to draw a conclusion for the study. According to the flowchart, nine critical steps were identified as the key elements in this methodology. The complete methodology is illustrated in the flowchart depicted in Figure 1 below:

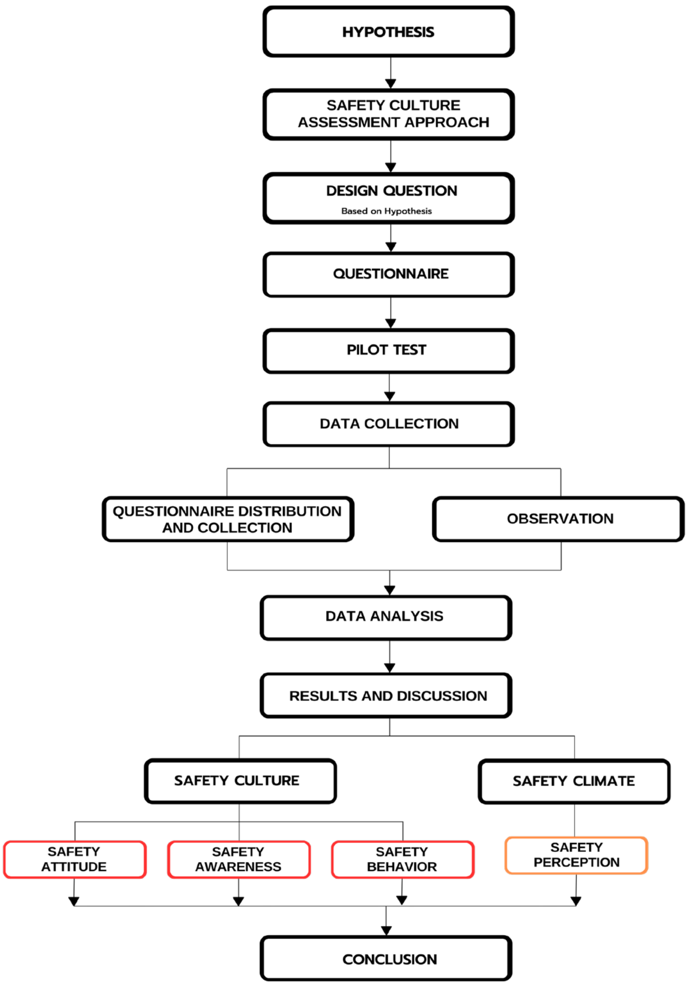

Figure 1. Flowchart

2.1 Formulation of Hypothesis

The identification of independent and dependent variables is essential in the development of research hypotheses. The independent variable is a variable in a research study that is intentionally manipulated in order to examine its impact on the dependent variable. In contrast, the dependent variable is the measurable factor that results from the manipulation of the independent variable. The variables used in this research are shown in **Table 1** and **Table 2**.

Table 1. The list of independent variables

No	Independent Variables
1	Age Group
2	Years of Study
3	Years of Laboratory Experience
4	Length of time spent working in the laboratory
5	Near-miss incident experience
6	Laboratory safety training experience

Table 2. The list of dependent variables and the factors influencing them

No	Dependent Variables	Factors
1	Safety Culture	Safety Attitude
		Safety Awareness
		Safety Behavior
2	Safety Climate	Safety Perception

Based on these variables, multiple hypotheses were formulated in order to investigate the relationships between variables in this research. The hypotheses in this research are:

(a) The age groups of students have significant differences on the safety culture and safety climate.
(b) The years of study of students have significant differences on the safety culture and safety climate.
(c) The years of laboratory experience of students have significant differences on the safety culture and safety climate.
(d) The length of time spent working in laboratory setting in a day by students have significant differences on the safety culture and safety climate.
(e) The near-miss incident experience of students has significant differences on the safety culture and safety climate.
(f) The laboratory safety training experience of students has significant differences on the safety culture and safety climate.
(g) There is correlation between safety culture and safety climate pattern.

2.2 Design of Question

The questionnaire covers socio-demographic section, safety attitude, safety awareness, safety behavior, and safety perception sections. The questionnaire consists of three stages which are planning and preparation, stakeholder engagement, and data collection and analysis. The first stage includes identifying relevant stakeholders, developing questionnaires and protocols, and establishing suitable framework for data collection. The second stage is distribution of questionnaires that involve engaging with relevant stakeholders, such as undergraduate students to gather their perspectives on safety culture [11]. The final stage involves systematic data collection by asking predetermined questions or addressing specific topics related to safety culture. The summary of the sections in the questionnaires as tabulated in **Table 3**.

Table 3. Design of Survey Questionnaire

Section	Contents	Number of Questions
Section A	Socio-Demographic	8
Section B	Safety Attitude	6
Section C	Safety Awareness	5
Section D	Safety Behaviour	7
Section E	Safety Perception	7

2.3 Pilot Study

A pilot study was conducted to assess the reliability of the questionnaire by verifying its capacity to yield the intended outcomes. In the pilot study, it is possible to make adjustments to the questionnaire by removing, modifying, or adding items in order to align with the research objectives. The questionnaire was created on the Google Form platform and then distributed through popular social media platforms such as WhatsApp, Telegram and Messenger. The participants selected for this study are undergraduate chemical engineering students of Faculty Chemical and Energy Engineering (FCEE). A total of 30 participants will be included in the pilot test. The distribution of the questionnaire and the subsequent analysis of the reliability test will be completed within a span of one week to ease the modification process.

Internal consistency is a concept that pertains to the degree of homogeneity among items, or the amount to which a set of items measures a particular construct [12]. Cronbach's Alpha will be used to assess the reliability of the scales representing the independent and dependent variables together. According to Nunnally (1978), a Cronbach Alpha coefficient greater than 0.7 is generally seen as indicative of better reliability, whilst coefficients below 0.7 are deemed less dependable [13]. Lack of reliability may arise from divergences between observers or instruments of measurement or instability of the attribute being measured. Cronbach's Alpha was used in Statistical Package for Social Sciences (SPSS) to assess the reliability of the variables' items. The internal consistency of the research question items of each variable will be measured and tabulated. Response from each respondent will be compiled in SPSS to determine the Cronbach's alpha.

2.4 Data Collection

A structured questionnaire was designed to capture data related to participants' safety culture in terms of safety attitude, safety awareness, safety behavior and safety perception. The questionnaire comprises a series of closed-questions using the Likert scale. The targeted participants for this study are undergraduate chemical engineering students actively involved in laboratory work. The questionnaires were prepared using Google Forms and distributed to the respondents during the laboratory sessions such as Separation Process 1 Laboratory and Fluid Mechanics Laboratory as well through social platforms such as WhatsApp, Facebook, Messenger, Instagram and Telegram. The data collection procedure was conducted from April 2024 to May 2024, achieving 110 number of participants. About 10-15 minutes was taken by the respondents to answer all the questions. The researcher assumes the role of an interviewer, distributing the questionnaire, and offering assistance to participants during the data collection process. All data and information that is gathered in this study are strictly confidential and shall not be accessed by any other without prior permission from the participants.

2.5 Data Analysis

In this work, the safety culture and safety climate among undergraduate chemical engineering students in academic laboratories of FCEE (Faculty of Chemical and Energy Engineering) were analyzed through SPSS 20 (IBM SPSS Statistics). The skewness and kurtosis of the data were examined to verify non normal distribution. The values were calculated using histograms. The data was analyzed using non-parametric methods. A study of sociodemographic traits will be done to verify the respondents' data. Analysis of the questionnaire results highlights prominent issues related to four key aspects which are safety attitude, safety awareness, safety behavior and safety perception. The Kruskal Wallis test, Mann-Whitney U test and Spearman Correlation test were applied in this study's analysis.

The Kruskal- Wallis Test is used to determine if there are statistically significant differences between two or more groups of an independent variable on a continuous or ordinal dependent variable. This approach will be utilized for hypotheses 1, 2, 3 and 4. The Kruskal Wallis test is classified as a non-parametric test. The association between age group, years of study, years of laboratory experience, and length of time spent working in the laboratory with the safety culture and safety climate of undergraduate chemical engineering students were analyzed through this approach.

The Mann-Whitney U test is used to compare differences between two independent groups when dependent variable is either ordinal or continuous, but not normally distributed. The Mann-Whitney U test can be employed to examine potential disparities in attitudes towards pay discrimination, with attitudes being assessed on an ordinal scale, across gender categories. In this scenario, the dependent variable would be "attitudes towards pay discrimination," while the independent variable would be "gender," comprising two groups: "male" and "female." The Mann-Whitney U test was used to evaluate hypotheses 5 and 6. This approach will be used to study the differences between near miss incident experience and laboratory safety training experience and safety culture and safety climate of undergraduate chemical engineering students.

Spearman's correlation analysis is a technique used to assess the strength of ordinal data, such as perceptions data. The Spearman correlation is a non-parametric statistical measure used to assess correlations between variables ranked in a certain order. Spearman's correlation technique is appropriate for examining relationships among Likert scale items. The range of Spearman's correlation coefficients is from -1 to +1. A positive correlation is shown when there is a simultaneous rise in both variables. Conversely, a negative correlation arises when there is an increase in one variable while the other variable tends to decline. Values approaching -1 or +1 suggest stronger correlations than values closer to zero. In this study, the researcher used Cohen's (1988) criteria to determine the magnitude of the link between two variables. The study assessed hypothesis number 7 using this method.

3.0 RESULTS AND DISCUSSION

3.1 Reliability Test

A pilot study was conducted to assess the reliability of the questionnaire by verifying the generation of the desired results. Internal consistency refers to the degree of homogeneity among the items used to test a concept [12]. In order to assess the dependability of the scales used to represent the independent and dependent variables together, Cronbach's Alpha was used. A Cronbach Alpha with a value greater than 0.7 is regarded to be more dependable than values below 0.7 [13]. The reliability of the variables' items was assessed using Cronbach's Alpha in SPSS Statistics. The research questions used to measure the safety behaviour of undergraduate students at chemical engineering laboratories have a high level of internal consistency, as shown by an alpha coefficient of 0.912. The research questions for all four (4) sections had a Cronbach's alpha value of more than 0.7, which indicates a high level of internal consistency and reliability. **Table 4**. shows the reliability test statistics Cronbach's Alpha.

Table 4. Reliability test statistics Cronbach's Alpha

Sections	Number of Items	Cronbach's Alpha
Safety Attitude	6	0.782
Safety Awareness	5	0.788
Safety Behaviour	7	0.912
Safety Perception	7	0.864

3.2 Socio-Demographic

The socio-demographic study of the undergraduate students consists of seven characteristics which are gender, age, years of study, years of laboratory experience, length of time spent working in the laboratory, number of near-miss incidents, and frequency of laboratory safety training. The demographic data indicated that majority of the participants were female participants (58.18%), with the majority falling within the age group of 21 to 23 years (68.18%). In terms of educational background, most participants have completed 3 to 4 years of study, accounting for 78.18% of the sample. 35.45% of the participants possess 3 to 4 years of laboratory experience, while nearly half (43.64%) report spending 1 to 2 hours in the laboratory during each session. The data further reveals that 50.91% of participants have encountered 1 to 2 near-miss incidents. Furthermore, a significant majority (57.27%) have undergone laboratory safety training 1 to 2 times, highlighting the importance of ongoing education in laboratory environments. **Table 5** shows the demographic characteristics of the respondents.

Table 5. Demographic characteristics of respondents

Variable	Classification	Frequency	Percentage
Gender	Female	64	58.18%
	Male	46	41.82%
Age	18-20 years	11	10.00%
	21-23 years	75	68.18%
	24-26 years	23	20.91%
	27-30 years	1	0.91%
Years of Study	1 year	0	0.00%
	2 years	22	20.00%
	3 years	41	37.27%
	4 years	45	40.91%
	More than 5 years	2	1.82%
Years of Laboratory Experience	1-2 years	31	28.18%
	3-4 years	39	35.45%
	Less than 1 year	22	20.00%
	More than 5 years	18	16.36%
Length of Time Spent in Laboratory	1-2 hours	48	43.64%
	2-4 hours	45	40.91%
	Less than 1 hour	3	2.73%
	More than 4 hours	14	12.73%
Number of Near Miss Incidents	0	48	43.64%
	1-2 times	56	50.91%
	3-4 times	5	4.55%
	More than 5 times	1	0.91%
Frequency of Laboratory Safety Training	0	22	20.00%
	1-2 times	63	57.27%
	3-4 times	19	17.27%
	More than 5 times	6	5.45%

3.3 Mean Score Analysis

3.3.1 Safety Culture

The safety culture of undergraduate chemical engineering students was assessed using three main dimensions, attitude, awareness and behaviour, which are fundamental aspects of safety culture according to Zohar (1980). From Figure 2(a), it can be concluded that the safety attitude of undergraduate chemical engineering students is moderate with an overall mean score of 3.13. The mean scores for safety attitude ranged from 3.65 to 2.82. From Figure 2(b), it can be concluded that the safety awareness of undergraduate chemical engineering students is moderate with an overall mean score of 2.66. The mean scores for safety awareness ranged from 3.05 to 2.25. From Figure 2 (c), it can be concluded that safety behaviour of undergraduate chemical engineering students is moderate with an overall mean score of 2.45. The mean scores for safety behaviour ranged from 2.84 to 2.13.

Similar results were obtained by Hasan and Younous (2020) in a study about Bangladeshi university students' safety culture who obtained an overall mean score of 3.70 for safety attitude and awareness, ranging from 3.47 to 4.01 and an overall mean score of 3.67 for safety behaviour, ranging from 3.25 to 4.04 [14]. The researcher's findings emphasized that the safety culture across the university is moderate and robust safety education is required to inculcate safety culture among the university students. Another research on the safety culture of Chinese undergraduate students obtained an overall mean score of 3.76 whereby the mean scores ranged from 2.48 to 4.72 [15]. This research identified the weakness in accident prevention activities and highlighted that effective interventions through safety education is required to improve the safety culture of undergraduate students.

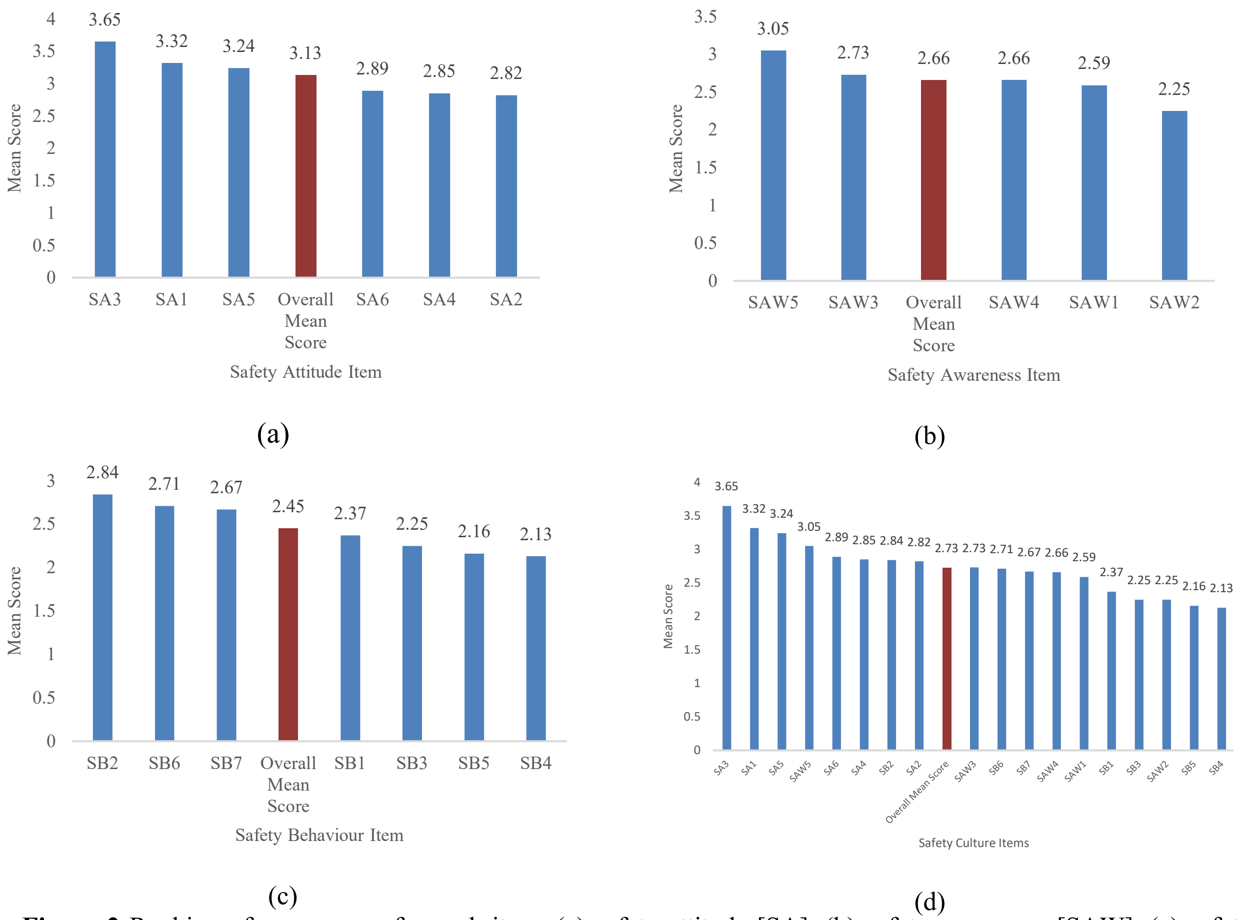

Figure 2 Ranking of mean score for each item: (a) safety attitude [SA], (b) safety awareness [SAW], (c) safety behaviour [SB], (d) overall safety culture

3.3.2 Safety Climate

The term "safety climate" refers to workers' general perceptions about their work environment [16]. It is a collective understanding or belief held by individuals or groups about a certain institution. In this study, the safety climate of undergraduate chemical engineering students was studied under Section E: Safety Perception. From Figure 3, it can be concluded that the safety perception of undergraduate chemical engineering students is moderate with an overall mean score of 2.48. The mean scores for safety perception ranged from 2.73 to 2.06.

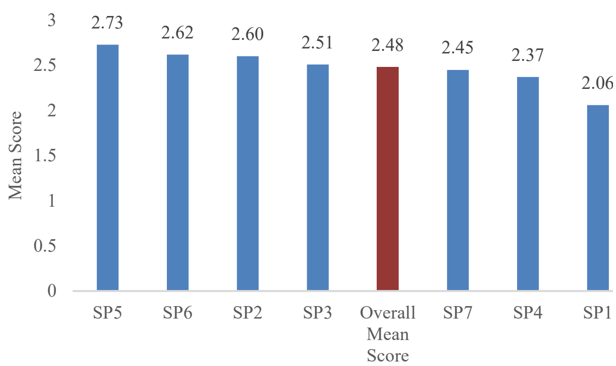

Figure 3. Ranking of mean score for each item of safety climate

3.4 Hypothesis Testing

3.4.1 Safety Culture

Table 6. Summary of Non-Parametrical Analysis of Safety Culture

Dependent Variables	Independent Variables	Test statistics (p-value)	Significance	Interpretation
Safety Culture	Age Group	K-W H = 7.912[a] (0.048)	Significant ($p>0.05$)	The students of higher age (older students) have higher safety culture.
	Years of study	K-W H = 9.272[a] (0.026)	Significant ($p>0.05$)	Students with more years of study have higher safety culture
	Years of laboratory experience	K-W H = 9.975[a] (0.019)	Significant ($p>0.05$)	Students with more years of laboratory experience have higher safety culture
	Length of time spent working in the laboratory	K-W H = 4.188[a] (0.242)	Not significant ($p<0.05$)	Students who spent long length of time have higher safety culture
	Near miss incident experience	M-W U = -0.109[b] (0.904)	Not significant ($p<0.05$)	Students with near miss incident experience have higher safety culture
	Laboratory safety training	M-W U = -3.046[b] (0.002)	Significant ($p>0.05$)	Students who attended laboratory safety training have higher safety culture

[a] K–W H refers to Kruskal-Wallis H value (X^2-Score)

[b] M-W U refers to Mann-Whitney U value (Z-Score)

Hypothesis 2 examines the effects of years of study on the safety culture of undergraduate chemical engineering students. As indicated by **Table 6**, the years of study show significant differences in safety culture, with a p-value of 0.026, which is lower than the standard alpha value of 0.05. This finding contrasts with the research of Blair et al. (2004), Faller et al. (2010), Gong (2019), and Hasan and Younos (2020), who found no significant effect of years of study on safety culture [17] [18] [15] [14]. Crowe (1995) found similar results, noting that senior undergraduate students have a greater sense of safety values than younger students. This could be explained by the influence of age, as discussed in Hypothesis 1. Promoting safety education throughout university tenure could enhance safety culture among students.

Hypothesis 3 explores the impact of years of laboratory experience on safety culture. **Table 6** indicates significant differences, with a p-value of 0.019, below the alpha value of 0.05. This finding aligns with Schroder et al. (2015), who noted that inexperienced students often overlook experimental risks, leading to higher accident rates [18]. Breslin and Smith (2006) found years of experience to be a strong predictor of occupational injury, independent of age [19]. Al-Abhar et al. (2017) also noted that more experienced employees possess greater safety knowledge and awareness due to training and experience. Hypothesis 4 investigates the effects of the length of time spent in the laboratory on safety culture, indicating no significant differences with a p-value of 0.242. However, students spending more than 4 hours in the laboratory have the highest level of safety culture, implying that extended exposure positively influences safety attitudes and practices, even if not statistically significant.

Hypothesis 5 examines the impact of near-miss incident experience on safety culture. **Table 6** shows no significant differences, with a p-value of 0.914. However, students who experienced near-miss incidents scored the highest mean rank, indicating a high level of safety culture. Samarayanake et al. (2022) highlighted the importance of stringent laboratory regulations due to frequent accidents [18]. Ismail and Ramli (2023) emphasized management's role in promoting safety culture by preventing accidents [20]. Hypothesis 6 investigates the impact of laboratory safety training on safety culture. **Table 6** shows significant effects, with a p-value of 0.002. This suggests that safety training enhances safety culture. Alkhaledi et al. (2023) found that older personnel with more training had lower accident rates, emphasizing the importance of training for younger employees [21]. Ismail and Ramli (2023) noted that effective training programs are crucial for fostering a strong safety culture [20].

3.4.2 Safety Climate

Table 7. Summary of Non-Parametrical Analysis of Safety Climate

Dependent Variables	Independent Variables	Test statistics (p-value)	Significance	Interpretation
	Age Group	K-W H = 2.197[a] (0.533)	Not significant ($p<0.05$)	The students of higher age (older students) have higher safety climate.
	Years of study	K-W H = 5.246[a] (0.155)	Not significant ($p<0.05$)	Students with more years of study have higher safety climate
	Years of laboratory experience	K-W H = 3.179[a] (0.365)	Not significant ($p<0.05$)	Students with more years of laboratory experience have higher safety climate
Safety Climate	Length of time spent working in the laboratory	K-W H = 8.982[a] (0.030)	Significant ($p>0.05$)	Students who spent long length of time have higher safety climate
	Near miss incident experience	M-W U = -0.091[b] (0.928)	Not significant ($p<0.05$)	Students with near miss incident experience have higher safety climate
	Laboratory safety training	M-W U = -2.025[b] (0.043)	Significant ($p>0.05$)	Students who attended laboratory safety training have higher safety climate

[a] K–W H refers to Kruskal-Wallis H value (X^2-Score)
[b] M-W U refers to Mann-Whitney U value (Z-Score)

Based on **Table 7,** there is no significant differences in safety climate across age groups, with a p-value of 0.533, which is higher than the standard alpha value of 0.05 for Hypothesis 1. This finding contradicts the results of Wu et al. (2007), who observed significant differences in safety climate among employees of different ages. Super (1957) supported Wu's findings by suggesting that older individuals are more comfortable with their working environment, while younger individuals, being less skilled and experienced, have a lower safety climate. The discrepancy in these findings may be due to the academic laboratory setting of this study, which might mitigate age-related differences in students' safety perceptions. For Hypothesis 2, **Table 7** shows no significant differences in safety climate based on years of study, with a p-value of 0.155, higher than the standard alpha value of 0.05. This suggests that students' perceptions of laboratory safety do not significantly change as they progress through their years of study. This could be due to safety climate being influenced more by overall environmental and organizational factors than individual characteristics.

Table 7 shows no significant differences in safety climate based on years of laboratory experience, with a p-value of 0.365 for Hypothesis 3. Wu et al. (2007) also found no significant impact of years of experience on safety climate. However, Kong et al. (2019) reported significant differences, suggesting that experienced individuals have better safety attitudes and teamwork abilities. This contradiction may be influenced by the nature of the work, organizational safety climate, and level of safety training provided. **Table 7** reveals significant differences in safety climate based on time spent in the laboratory, with a p-value of 0.030 for Hypothesis 4. Students spending more than 4 hours have the highest safety climate levels. Samaranayake et al. (2022) found that participants spending over 40 hours per week exhibited high safety perceptions, attributing this to increased familiarity with safety protocols and hazards [22].

For Hypothesis 5, **Table 7** shows no significant differences in safety climate based on near-miss experience, with a p-value of 0.928. Despite this, students with near-miss experience scored the highest mean rank. Wu et al. (2007) found significant differences in safety climate between individuals with and without accident experience, suggesting that such experiences enhance safety attitudes and awareness [1]. **Table 7** indicates that safety training significantly impacts safety climate, with a p-value of 0.043 for Hypothesis 6. Wu et al. (2007) also found that multiple training sessions improve safety climate perceptions [1]. Blair et al. (2004) and Crowe (1995) highlighted the importance of safety training in promoting safety culture, noting significant changes in personal accountability due to training [17]. Overall, laboratory safety training positively impacts safety culture and climate, promoting proactive safety attitudes and minimizing accidents.

3.5 Relationship between Safety Culture and Safety Climate

Table 8. Hypothesis 7 Spearman Correlation test between Safety Culture and Safety Climate

Correlations				
			Safety Climate	**Safety Culture**
Spearman's rho	Safety Climate	Correlation Coefficient	1.000	.694**
		Sig. (2-tailed)	.	<.001
		N	110	110
	Safety Culture	Correlation Coefficient	.694**	1.000
		Sig. (2-tailed)	<.001	.
		N	110	110

**. Correlation is significant at the 0.01 level (2-tailed).

Based on **Table 8** , there is a significant relationship between safety culture and safety climate of undergraduate chemical engineering students. This is explained by the R-value (0.694) being more than 0.50 and the p-score (0.001) being less than 0.005. Although no previous researchers have specifically studied the correlation between safety culture and safety climate, these findings highlight an important connection.

Safety culture was initially introduced by the International Atomic Energy Agency (IAEA) following the catastrophic incident at Chernobyl. It encompasses a mixture of individuals' values, attitudes, beliefs, and behaviours regarding the safety of workers and the overall safety of the work environment within an organizational context. Cox et al. (1991) defined safety culture as a reflection of the attitudes, beliefs, perceptions, and values that employees share in relation to safety. The Advisory Committee on the Safety of Nuclear Installation (ACSNI) further states that the safety culture of an organization is the product of individual and group values, attitudes, perceptions, competencies, and patterns of behaviour that determine the commitment to, and proficiency of, an organization's health and safety management.

Safety climate, on the other hand, was first introduced in 1980 by Zohar, who defined it as a collective perception of safety policies, procedures, and practices [16]. Kennedy et al. (1998) referred to safety culture as a sub-element of the overall organizational culture, influenced by the amalgamation of individual and group perceptions, thought processes, feelings, and behaviours. Hale (2000) stated that safety culture includes the attitudes, beliefs, and perceptions shared by natural groups, determining how they act and react in relation to risks and risk control systems [23].

The relationship between safety culture and safety climate is underpinned by the interaction of individual attitudes, awareness, and behaviour towards safety (safety culture) and the collective perceptions of safety policies and practices (safety climate). For example, Griffin et al. (2016) referred to safety culture as the underlying assumptions and values that guide behaviour in organizations, rather than the direct perceptions of individuals [24]. Jiang (2022) stated that safety culture involves conceptual elements such as attitudes, ideas, values, perceptions, and beliefs.

The significant correlation between safety culture and safety climate suggests that a strong safety culture, characterized by positive safety attitudes, high safety awareness, and safe behaviours, contributes to a positive safety climate. This emphasizes the importance of fostering a robust safety culture to enhance the overall safety climate within an organization. The definitions of safety culture by these previous researchers prove that safety culture, predominantly influenced by individuals' attitudes, awareness, and behaviours towards safety, has a significant relationship with safety climate, which emphasizes the element of individuals' perception towards safety. Therefore, improving safety culture can lead to better safety perceptions and a stronger safety climate, ultimately creating a safer working and learning environment.

3.6 Strategies to Foster Safety Culture and Safety Climate

The direct participation of lab supervisors in safety monitoring within academic institutions has a positive effect on safety behaviour and leads to a decrease in laboratory accidents. It is important to increase knowledge about the crucial role that principal investigators (PIs) and laboratory supervisors play in academic institutions. During training sessions and lab inspections, it is crucial for Universiti Teknologi Malaysia (UTM)'s Occupational Safety, Health and Environment (OSHE) unit to prioritize and highlight the responsibility of supervisors. Moreover, using an instructional strategy that involves department chairman in faculty meetings may effectively emphasize the significance of the supervisor's proactive involvement in maintaining laboratory safety. The researchers are motivated to adopt safer procedures when the principal investigators (PIs) consistently prioritize lab safety [18].

Furthermore, the integration of safety education into the undergraduate curriculum is crucial, as students with more understanding of safety demonstrate a heightened safety culture [15]. It is recommended to provide goal-oriented safety education, which includes frequent safety training, seminars, and exercises, for both undergraduate students [14]. Implementing safety passport courses and assessments that students must complete and pass before to engaging in laboratory work is an additional successful approach. Providing students with hands-on practical sessions for physical training instead of virtual training might provide them more exposure to laboratory safety.

A blended learning strategy for safety education may effectively strengthen the safety culture. This strategy incorporates a combination of integrated videos, lecture materials, tasks, and independent conversations inside a virtual learning platform (VLE). The Virtual Learning Environment (VLE) has the capability to store and present reusable learning objects (RLOs) that provide learning opportunities at the right moment and accommodate various learning preferences. This encompasses several types of evaluations such as end-of-semester examinations, brief tasks, conversations conducted inside the Virtual Learning Environment (VLE), and the fulfilment of RLO assessments.

Next, the faculty should implement a comprehensive accident, near-miss, and injury reporting system with a friendly communication structure is another vital approach. This technique promotes a sense of security among students, allowing them to report occurrences without worrying about punishment. Institutions may gather useful data by promoting open communication, which allows them to recognize patterns, conduct preventative measures, and improve safety standards. In order to enhance involvement and openness in safety reporting, it is advisable to include regular feedback sessions and provide anonymous reporting alternatives.

Integrating a process safety course into the curriculum during the first year of study helps provide students with fundamental understanding of safety concepts from the beginning of their academic pursuit. Students will be exposed to concepts of safety from the early days of their academic period which will enhance their safety culture throughout their period of study. In addition, implementing a consistent and ongoing safety training programme during the whole four-year study period guarantees that safety knowledge is consistently reinforced and routinely updated.

Last but not least, the utilization of Virtual Reality (VR) to simulate probable accidents, safe handling of hazardous substances, and emergency response situations in the laboratory presents a novel method for safety training. Virtual Reality (VR) offers a secure and regulated setting in which pupils may rehearse and internalise safety protocols without the potential for real-life repercussions. This immersive technology has the ability to improve comprehension and memory of safety rules, so equipping students with improved readiness to manage any undesired situations arising in the laboratories.

4.0 CONCLUSION

In conclusion, this study systematically examined the safety culture and safety climate among undergraduate chemical engineering students. The findings indicate that various demographic factors, including age, years of study, laboratory experience, and participation in safety training, significantly influence students' safety attitudes, awareness, and behaviors. Specifically, older students and those with greater laboratory experience exhibited a more developed safety culture, highlighting the crucial role of exposure and training in fostering safety-conscious practices.

Furthermore, the investigation into safety climate revealed that the duration of time spent in laboratory settings and participation in safety training programs significantly enhanced students' safety perceptions. Those who engaged more extensively in laboratory activities demonstrated a heightened understanding of safety protocols and hazards, contributing to a more robust safety climate.

To improve the safety culture and climate among undergraduate chemical engineering students, several strategic measures were recommended. These include reinforcing the role of laboratory supervisors in promoting safety, integrating continuous safety training throughout the curriculum, and revising safety courses to incorporate hands-on practical experiences. Additionally, the utilization of innovative learning methods, such as virtual learning environments and Virtual Reality simulations, is suggested to enhance safety education. Collectively, these initiatives aim to instill a comprehensive safety-first mentality within the undergraduate curriculum, thereby improving the overall safety culture and climate in academic laboratories.

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REFERENCES

[1] Wu, T.C., Liu, C.W., & Lu, M.C. (2007). Safety climate in university and college laboratories: Impact of organizational and individual factors. *Journal of Safety Research*, 38, 91–102.
[2] Michalovic, M. (2008). Not-so-great moments in chemical safety. *Chemical Heritage News Magazine*, 26(2).
[3] García-Martínez, J., Bermejo-Barrera, P., & Moreda-Piñeiro, A. (2016). Laboratory chemicals for academic research and teaching: A technological challenge for analytical chemistry. *Analytical and Bioanalytical Chemistry*, 408(10), 2409–2416.
[4] Skoog, D.A., Holler, F.J., & Crouch, S.R. (2013). *Principles of Instrumental Analysis*. Cengage Learning.
[5] Hill, R.H. (2016). The impact of OSHA's Laboratory Standard on undergraduate safety education. *Journal of Chemical Health and Safety*, 23(5), 12–17.
[6] Pourang, N., Esmaeili, F., & Ranjbarian, M. (2017). Assessment of potential safety hazards of three fisheries research centers' laboratories staff by failure modes and effect analysis (FMEA) and the relevant statistical methods. *Iran Journal of Health and Environment*, 10, 87–102.
[7] Kinderlerer, J. (2004). Risk and the law: Scientists do not necessarily like the restrictions and regulations of biotechnology, but they need to accept that lawmakers must reflect the wishes and demands of the majority of the population, who are increasingly aware of the potential risks. *EMBO Reports*, 5, S66–70.
[8] Menard, A.D., & Trant, J. (2019). A review and critique of academic lab safety research. Retrieved from https://pubmed.ncbi.nlm.nih.gov/31740762/.
[9] Bena, A., Farina, E., Orengia, M., & Quarta, D. (2016). Promotion of safety culture in Italian schools: Effectiveness of interventions on student injuries. *European Journal of Public Health*, 26, 587–592.
[10] Walters, A.U.C., Lawrence, W., & Jalsa, N.K. (2017). Chemical laboratory safety awareness, attitudes, and practices of tertiary students. *Safety Science*, 96, 161–171.
[11] Wu, Q., Li, W., Li, Y., Wu, X., & Xie, H. (2019). The effects of chemical hazards on reproductive and developmental toxicity. *Environmental Science and Pollution Research International*, 26(35), 35696–35705.
[12] Henson, R.K. (2001). Methods, plainly speaking. Understanding internal consistency reliability estimates: A conceptual primer on coefficient alpha. 34, 177–189.
[13] Nunnally, J.C. (1978). An overview of psychometric measurement. 97–146.
[14] Hasan, M.K., & Younos, T.B. (2020). Safety culture among Bangladeshi university students: A cross-sectional survey. *Journal of Safety Science*, 131, 104922.
[15] Gong, Y. (2019). Safety culture among Chinese undergraduates: A survey at a university. *Safety Science*, 111, 17–21.
[16] Zohar, D. (1980). Safety climate in industrial organizations: Theoretical and applied implications. *Journal of Applied Psychology*, 65(1), 96–102.
[17] Blair, E.H., Seo, D.-C., Torabi, M.R., & Kaldahl, M.A. (2004). Safety beliefs and safe behavior among Midwestern college students. *Journal of Safety Research*, 35(2), 131–140. doi:10.1016/j.jsr.2003.11.003.
[18] Faller, G., Mikolajczyk, R.T., Akmatov, M.K., Meier, S., & Krämer, A. (2010). Accidents in the context of study among university students—A multicentre cross-sectional study in North Rhine-Westphalia, Germany. *Accident Analysis and Prevention*, 42, 487–491.
[19] Breslin, F.C., & Smith, P. (2006). *Occupational and Environmental Medicine*, 63(1), 27–32.
[20] Ismail, S.N., & Ramli, A. (2023). Investigate the factors affecting safety culture in the Malaysian mining industry. *Resources Policy*, 85, 103930.
[21] Alkhaledi, K.A., Bendak, S., & Dashti, F.A. (2023). Assessing safety culture in public sector organisations: A cross-national study. *International Journal of Industrial Ergonomics*, 94, 103425.
[22] Samaranayake, A.I., Nishadya, S., & Jayasundara, U.K. (2022). Analyzing safety culture in Sri Lankan industrial chemical laboratories. *Safety and Health at Work*, 13(1), 86–92.
[23] Thamrin, Y., Pisaniello, D., & Stewart, S. (2010). Time trends and predictive factors for safety perceptions among incoming South Australian university students. *Journal of Safety Research*, 41, 59–63.
[24] Griffin, M.A., & Neal, A. (2000). Perceptions of safety at work: A framework for linking safety climate to safety performance, knowledge, and motivation. *Journal of Occupational Health Psychology*, 5(3), 347.
[25] Hale, A.R. (2000). Culture's confusions. *Safety Science*, 34(1–3), 1–14.
[26] Wells, G. (1997). *Hazard identification and risk assessment*. Rugby, Warwickshire: Institution of Chemical Engineers (IChemE).
[27] Schröder, I., Huang, D.Y., Ellis, O., Gibson, J.H., & Wayne, N.L. (2016). Laboratory safety attitudes and practices: A comparison of academic, government, and industry researchers. *Journal of Chemical Health and Safety*, 23(1), 12–23.
[28] Suárez-Cebador, M., Rubio-Romero, J.C., Carrillo-Castrillo, J.A., & López-Arquillos, A. (2015). A decade of occupational accidents in Andalusian (Spain) public universities. *Safety Science*, 80, 23–32.
[29] Yang, K. (2013). Influencing factors on undergraduate students' response behaviors in case of fires in dormitories. *Journal of Chifeng University (Natural Science Edition)*, 29(8), 38–42.

[30] Yang, X. (2019). The reason for the explosion accident in Beijing Jiaotong University: It is the teacher's negligence that killed the students. *China Youth*. Retrieved from https://baijiahao.baidu.com.
[31] Zafar, S. (2023). 5 different types of risk assessment: Step by step guidance. Retrieved from https://www.hseblog.com/types-of-risk-assessment/.

Appendix A Survey Questionnaire

Label	Questions	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
Safety Attitude						
SA1	I report any accident/incident/ near miss to my supervisor or lecturer					
SA2	I participate in laboratory safety training provided by faculty					
SA3	I pay attention to safety instructions while I was working in a lab (e.g. Never pour chemical waste down the sink or into regular trash bins)					
SA4	I adhere to necessary safety measure during laboratory works (e.g. wearing appropriate personal protective equipment (PPE), including lab coats, safety goggles, and gloves, when conducting experiments in the laboratory)					
SA5	I rectify my mistakes when people point out my unsafe behaviour					
SA6	Completing my work is more important than doing work in safe ways					
Safety Awareness						
SAW1	I know the procedures to use a fire extinguisher (e.g. P.A.S.S. technique)					
SAW2	I know the procedures of emergency in case of fire break outs					
SAW3	I know the position of exits doors from laboratory					
SAW4	I know the position of first aid kit in the laboratory					
SAW5	I am aware of and understand the Occupational Safety, Health, and Environment (OSHE) Policy and Objectives of UTM					
Safety Behaviour						
SB1	I wear necessary personal protective equipment (PPE) during laboratory works					
SB2	I follow the laboratory regulation on storage and usage of hazardous chemicals					
SB3	I follow the safety signs to behave safely in the campus (e.g. No Smoking, No Food or Drink Allowed, Authorized Personnel Only)					
SB4	I enter a building following the designated directions or routes					
SB5	I exit a building following the designated directions or routes					
SB6	I report any hazard to my supervisor or lecturer					
SB7	I switch off electrical equipment or appliances when I leave the laboratory for a long time					
Safety Perception						
SP1	The laboratory where I work is a safe place to conduct experiments					
SP2	Laboratory safety rules improves productivity					
SP3	My supervisor or lecturer ask my opinion on how to improve safety conditions					
SP4	My supervisor or lecturer regularly checks whether I comply with safety procedures					
SP5	The lecturer or supervisor gives a safety briefing to students prior to doing experimental work					
SP6	The faculty equipped laboratory with preventive measures for safety at laboratory (e.g. Fumehood, Eye Wash Station, Emergency Shower)					
SP7	Laboratory safety regulations enforced by my supervisor or lecturer are stringent					