A Systematic Review on Hazard Identification, Risk Assessment and Risk Control in Academic Laboratory

Nor Aimi Abdul Wahab[1,*], Nur Athyratul Aqila[2], Norain Isa[2], Nurul Izza Husin[1], Azrinawati Mohd Zin[1], Marina Mokhtar[1], Nur Maizatul Azra Mukhtar[3]

[1] Department of Applied Sciences, Universiti Teknologi MARA, Cawangan Pulau Pinang, Kampus Permatang Pauh, Malaysia
[2] School of Chemical Engineering, College of Engineering, Universiti Teknologi MARA, Cawangan Pulau Pinang, Kampus Permatang Pauh, Malaysia
[3] Faculty of Health Sciences. Universiti Teknologi MARA, Cawangan Pulau Pinang, Kampus Bertam, Malaysia

ABSTRACT

Laboratory work, practical work, and practical work-related experiments are usually carried out in academic laboratories. Laboratory users are continuously exposed to hazardous substances and equipment in the laboratory. Limited research has been conducted on risk assessment in academic laboratories. However, there is no comprehensive review on hazard identification and risk assessment in the academic laboratory. Thus, this paper presents an overview of the academic laboratory's risk assessment, focusing on the risk assessment method, type of hazard, and control measures applied to eliminate the hazard. A total of 61 publications were identified from Scopus, IEEE Explore, and manual searching. The study was guided by PRISMA, and after the screening and eligibility process, 13 publications were selected and reviewed. Fifteen risk assessment methods were identified in the publication, with 53.3 % applied semi-quantitative method, 26.7% qualitative method and 20% quantitative method. For hazard identification, 54% discussed specific hazards, while 46% discussed non-specific hazards. Most of the hazard discussed was chemical hazard due to the hazardous nature of the chemical, the usage of chemical to conduct experiments in the laboratory, and the type of laboratory assessed which is mainly chemical laboratory. Most of the publications used at least more than one control measure to overcome the risk. The most common control measure applied is the combination of engineering control, administrative control, and personal protective equipment (PPE). In future work, simple, fast, low cost and efficient risk assessment is needed to aid academic laboratories in further improving laboratory risk management. A combination of qualitative and quantitative risk assessment methods may be required to enhance the risk assessment process by utilizing the positive aspect of both approaches. An online risk assessment may be needed to effectively communicate the risk to laboratory users to eliminate or reduce accident cases in the academic laboratory

Keywords:
Hazard; risk assessment; academic
laboratory; control measure

1. Introduction

An academic laboratory is a place where laboratory work and practical work-related experiments are conducted. Notably, practical work aid in understanding the science concept, enhancing problem-solving abilities and developing researchers' manipulative and observational skills [1]. The academic

---

laboratory is also used to test theories and nurture scientific knowledge [2]. Laboratory works expose laboratory users to various hazards such as chemical hazards, biological hazards, physical hazards, and ergonomic hazards. It requires users to deal with different materials and equipment. Numerous accidents in the academic laboratory have been reported worldwide where laboratory personnel consist of staff and students who experience and suffer injuries or, worse, fatalities. The accident rate in academic laboratories is about 10-50 times higher than in industrial laboratories [3]. In 2008, the University of California reported the death of a staff researcher, Sheharbano Sangji, due to a fire caused by the ignition of tert-butyllithium in a chemistry laboratory [4]. On April 5 2015, a gas cylinder in the laboratory of Xuzhou exploded and caused four injuries and the death of a graduate student. Another accident was reported on December 26, 2018, in a laboratory in Beijing, with three reported deaths due to an explosion while researching wastewater treatment [5][6]. In general, laboratory accidents were usually caused by unsafe acts and unsafe conditions. According to [5], the main caused of laboratory accidents are violations of operation rules, equipment ageing, failure or defect, wires ageing and short circuit, and improper operation. [6] state that the contributing factors in laboratory accidents are related to the risk associated with the materials or equipment being used and the skills and knowledge of the research personnel. According to [7] , 49% of the accidents at university campuses in Taiwan were related to the improper use of chemicals.

Accident cases in the academic laboratory may have a negative impact on the university. A high rate of accidents affects the profitability and accountability of a respective company. It also contributes to decreased efficiency, reduced productivity, and increased psychological effects, including anxiety and depression among laboratory users. The investigation findings from accident cases often indicate the absence of a hazard identification or risk analysis as a root cause factor [8][9]. Thus, the academic laboratory must ensure safety to reduce and prevent accidents and secure laboratory users' safety and welfare. It can be achieved by implementing risk management. Risk management is the process of identifying, assessing, and controlling threats suitable to the organization. It helps identify and prepare for potential risks, avoid catastrophic consequences, and ensure safety. Therefore, there is an urgent need for risk assessment practice in the academic laboratory to reduce accident cases.

This paper presents an overview of the risk assessment in the academic laboratory. The objectives of this paper are to (i) provide a review on the risk assessment method applied in the academic laboratory; (ii) to discuss the type of hazard commonly found in the academic laboratory; and (iii) to address various control measures applied to overcome or eliminate the hazard.

2. Methodology

2.1 Formulation of the research question

This section discusses the method used to retrieve articles related to hazard identification and risk assessment in academic laboratories. This simple systematic literature review was guided by reporting guidelines as proposed by Xiao and Watson [10]. This section explains the resources, inclusion and exclusion criteria, systematic review process, and data collection. Research questions were developed to identify the focus area. The research questions were created with the assistance of the PICo concept, which refers to population or problem, interest, and context [11]. The three main aspects based on the PICo concept are hazard (problem), risk assessment (interest) and academic laboratory (context), which led to the research question of -what are the risk assessment

method practised in the academic laboratory to identify the hazard.

2.2 The systematic review process for selecting articles.

The main process in the systematic review process for selecting articles includes identification, screening, and eligibility.

2.2.1 Identification

The identification process is carried out to provide more options to search for the article in the selected database. It is carried out by searching the synonyms, related terms, and variation of main keywords: hazard, risk assessment, and academic laboratory. The selection process of a research article was conducted using two primary databases: Scopus and IEEE explore. These databases were selected due to the comprehensive coverage of high-quality papers in top-level subject fields. A list of search strings was created by integrating appropriate synonyms based on thesaurus with the BOOLEAN operator OR and AND. OR serves to broaden and expand the source, while AND can limit and narrow the search. The search string is listed in Table 1. Manual searching was also applied to include relevant journal and conference proceedings in the related area using established sources such as Scopus and Google Scholar. The search process managed to identify a total of 56 articles from both databases. Manual searching adds another five articles.

Table 1
A list of search string

Source	Database search string
Scopus	TITLE-ABS-KEY (("hazard identifi*" OR "risk identifi" OR "threat identifi*" OR "risk assessment" OR "risk evaluation" OR "risk rating") AND ("academic laborator*" OR "teaching learning laborator*" OR "school laborator*" OR "university laborator*" OR "college laborator*"))
IEEE	(("hazard identification OR "risk identification OR "threat identification" OR "risk assessment" OR "risk evaluation" OR "risk rating") AND ("academic laboratory OR "teaching learning laboratory" OR "school laborator*" OR "university laboratory"))

2.2.2 Screening

The process continues with screening the article to determine whether to include or exclude the article based on the inclusion and exclusion criteria. The inclusion and exclusion criteria are given in Table 2. Articles published between 2011 to 2020 was selected to be reviewed. Exposure of interest was focused on risk management, and only English language articles were included to avoid confusion. For document type, only journal and conference proceedings were selected for the review process. The screening process has excluded 35 articles as they did not fit the inclusion criteria, and three duplicated articles were removed. A total of 23 articles were selected for the eligibility process.

Table 2
Inclusion and Exclusion Criteria

Criteria	Inclusion	Exclusion
Date	Within ten years period	More than ten years period journals
Exposure of Interest	Risk management	Overview of safety and hazard.
Language	English language	Other than English
Type of publication	Journal and conference proceeding	Books, chapter in book

2.3.3 Eligibility

The selected articles were thoroughly examined in the eligibility stage to ensure all the articles fit the required criteria. A total of 23 articles were reviewed where the title, abstract and content were carefully examined to ensure they fulfilled the inclusion criteria and related to the study's objective. A final of 13 articles was selected and use in this study.

2.3.4 Data abstraction and analysis

The 13 articles selected were assessed and analyzed by experts. The articles were thoroughly checked for points to answer the research question. Data were extracted from the article, which focuses on risk assessment methods, hazards, and control measures to eliminate hazards in the academic laboratory.

3. Result and discussion

3.1 Yearly Distribution

This study performed an integrative comparison review of diverse research on academic laboratories on hazard identification and risk assessment. In developing selected quality data, information and data that meets the research questions were analyzed from 13 selected articles (N=13) published within ten years. Eleven articles were published in journals, whereas two articles were published in conference proceedings. Figure 1 shows the trend of publication for the past ten years. The data shows a fluctuating trend over time, with the highest number of publications in 2019 with four publications. The data indicates that limited research has been published in this area even though laboratory safety is crucial in academic laboratories, as users are mostly novice users.
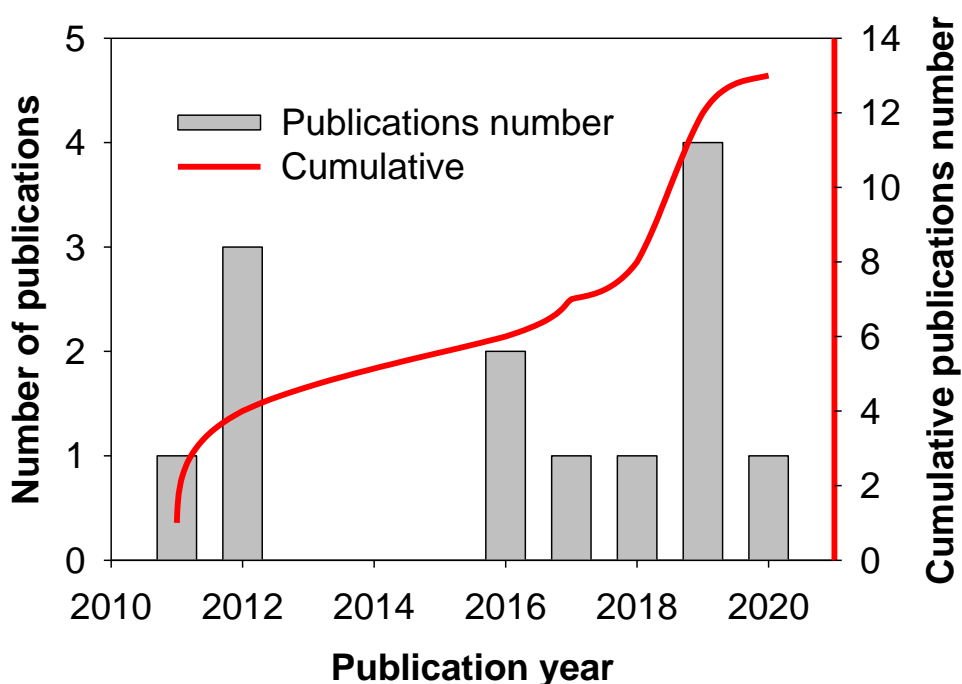

Fig.1. Number of Articles Published Within ten years

3.2 Risk Assessment Method

Researchers used various methods to present the hazardous situation and analyzed the risk of each hazard identified, as illustrated in Table 3. The risk assessment method can be classified as a qualitative, semi-qualitative and quantitative method. From the 15 methods applied, it was found that 53.3% used the semi-quantitative method, 26.7% qualitative method and 20% quantitative method, as illustrated in Figure 2. The Semi-qualitative method has been applied by [12] using semi-quantitative risk assessment (SQRA), [13][14] using Hazard Identification, Risk Assessment and Risk Control (HIRADC), [3][8,9] using Lab-HIRA, [15] using Chemical Health Risk Assessment (CHRA), and [16] using Hazard Identification, Risk Assessment and Risk Control (HIRARC). In the semi-quantitative method, the hazard identification part is primarily qualitative as it pre-defines the hazard. In contrast, in risk assessment, the research is quantitative, where it calculates the degree of risk in numerical for a specific hazard. The semi-quantitative risk assessment is preferable due to its simplicity compared to the quantitative method, while the qualitative method is too subjective.
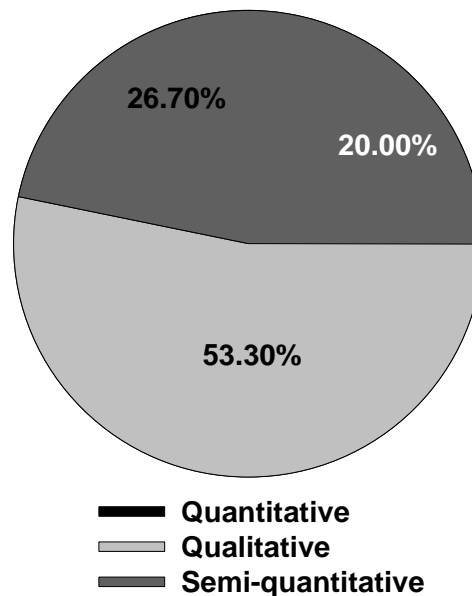
Fig.2. Type of Risk Assessment Method

Table 3
Risk Assessment in Academic Laboratory

Article	Year	Publication	Country	Laboratory type	Method	Hazard	Control Measure	
[17]	2017	Human and Ecological Risk Assessment Journal	Turkey	Chemical laboratory	5s FMEA Interval type-2 fuzzy sets AHP VIKOR	Chemical Electrical Physical Psychological Ergonomic	Engineering	1. Maintenance of AAS. 2. Fixing gas cylinder and TGA to wall. 3. Changing surface material of benches and sink. 4. Increasing depth of sink. 5. Installing a ventilation system.
							Administrative	1. Defining work area. 2. Independent lab for organic chemicals. 3. Providing eye wash and safety shower. 4. Implementing buddy system 5. Purchasing gas sensor 6. Prepare SOP 7. Training
							PPE	1. PPE depending on the hazard.
[12]	2016	Journal of Occupational Health and epidemiology	Iran	Chemical laboratory	Chem-SAM UOW SQRA	Chemical	Engineering	1. Improving local exhaust ventilation system
							Administrative	1. Training
							PPE	1. PPE depending on the hazard.
[13]	2019	Indian Journal of Public Health Research and Development	Indonesia	Nutrition laboratory	HIRADC	Chemical Physical Elctrical Biological	Engineering	1. Placing LPG far from flammable substances at stable temperature.
							Administrative	1. Prepare SOP. 2. Briefing on safety practice. 3. Training. 4. Procuring First Aid Kit.
							PPE	1. PPE depending on the hazard

Ref	Year	Journal	Country	Setting	Method	Hazard	Control	Recommendation
[14]	2020	Indian Journal of Forensic Medicine & Toxicology	Indonesia	Laboratory of Histology Anatomy	HIRADC	Chemical Physical Biological Psychological Ergonomic	Engineering	1. Improve the ventilation system.
							Administrative	1. Training. 2. Providing fire extinguisher. 3. Briefing on job scope 4. Implementing buddy system. 5. Prepare SOP.
							PPE	1. PPE depending on the hazard
[3]	2012	Process Safety Progress	United State	Research laboratory	LAB-HIRA	Chemical	Administrative	1. Review on handling procedures of chemical. 2. Developing emergency procedures for spill and fire.
							PPE	1. PPE depending on the hazard
[8][9]	2012	Journal of Chemical Health and Safety	United State	Chemical Research laboratory	LAB-HIRA	Chemical	Engineering	1. Installing alarm that would switch off equipment in hazardous situation.
							Administration	1. Follow-up by university's SHE group to ensure risk reduction recommendation has been carried out 2. Using small scale reactions and avoid overnight runs for certain reactions.
							PPE	1. PPE depending on the hazard.

[18]	2019	International Journal of Environmental Research and Public Health	China	School laboratory	Bayesian Network	Chemical	Engineering	1. Improve the ventilation system of the laboratory.
							Administrative	1. In-depth knowledge on the content and specification of the experiment 2. Implementation of the safety responsibility system
							PPE	1. PPE depending on the hazard
[15]	2019	International Journal of Environmental Health Research	Iran	Water and Wastewater Chemistry Chemical Agent and Air Pollutants Microbiology Industrial Toxicology	CHRA and RSLs	Chemical	Engineering	1. Improve ventilation system
							Administrative	1. Repetition of training programs every 2 years 2. Preparation of database and safety data sheet for chemical 3. Development of air sampling plan and biological monitoring for high risk material
							PPE	1. Special PPE for certain material.
[19]	2019	IOP Conference Series: Material Science and Engineering	Indonesia	Research laboratory	Risk Identification, risk assessment and risk analysis	Chemical Physical Electrical	Administrative	1. Provide safety procedures 2. Control access to equipment/tools
							PPE	1. PPE depending on the hazard

[20]	2011	CHIMIA	Switzerland	Chemistry laboratory	MICE	Chemical Physical Electrical Biological	Administrative	1. laboratory door panel labeling indicating the top three hazards present in the room. 2. MICE management of chemical 3. Chemical inventory in a dynamic central database 4. Workplace audit control 5. Training for researchers 6. Marking work area based on magnetic field intensity 7. Assembled safety nanosafe team
							PPE	1. PPE depending on the hazard
[21]	2016	Journal of Chemical Health and Safety	USA	Chemistry laboratory	Bowtie	Chemical	Administrative	1. Safety training 2. Proper maintanence
							PPE	1. PPE depending on the hazard
[16]	2018	AIP Conference Proceeding	Indonesia	Production System Laboratory	HIRARC 5s	Physical Mechanical	Engineering	1. Install exhaust fan 2. Machine maintenance
							Administrative	1. Prepare SOP 2. Safety briefing 3. Audit 4. Warning signage 5. limit operating time for noise exposure
							PPE	1. PPE depending on the hazard

A qualitative risk analysis was conducted by [12] using chem-SAM and University of Wollingong (UOW) risk assessment, [20] using MICE and [21] using the bowtie method. Qualitative risk assessment has the advantage of being simple and rapid assessment. However, evaluation by qualitative risk assessment is primarily subjective, highly dependent on team experience and does not allow for determination of probabilities and result using numerical measure [22]. Risk assessment for quantitative method has been applied by [17] using Analytical Hierarchy Process (AHP), VIKOR techniques, [18] using Bayesian Network (BN) and [15] using Regional Screening Levels (RSLs). Not many researchers applied quantitative methods for risk assessment in academic laboratories as it is more complicated and demanding resources and skills. It could also be due to the risk in academic laboratories is not as severe as the risk in the industry. The data collection method varies from doing a questionnaire to the software-based method.

More than half of the publications use Hazard Identification, Risk Assessment Risk Control (HIRARC) or Hazard Identification, Risk Assessment and determining Control (HIRADC) to identify the hazard and assess the risk. HIRARC or HIRADC widely uses for risk assessment due to its simplicity and straightforward approach. HIRARC requires four simple steps: classify work activities, identify the hazard, conduct risk assessment, and decide whether the risk is acceptable or need control measure. [13],[14],[3],[8],[9],[16] [13] apply HIRARC/HIRADC to evaluate the risk faced by laboratory users. Hazard identification has been carried out using various ways, namely through observation [14],[13],[16], interview session [16] and chemical hazard review [8],[9],[3]. The chemical's physical, chemical, toxicological and exposure characteristics were considered in the chemical hazard review to identify the hazard that may arise from the use of hazardous chemicals. Lab-HIRA conducted by [8],[9] uses a software tool that provides a systematic approach to risk assessment. The risk assessment for each hazard must be performed based on the hazard's likelihood of occurrence and severity. Risk estimation will be determined by considering the magnitude of the risk and whether the risk is tolerable or needs control measures to eliminate or reduce the risk.

[17] proposed an approach for risk assessment in a chemical laboratory using incorporated 5s methodology, failure mode and effect analysis (FMEA), interval type-two fuzzy sets (IT2FSs), analytic hierarchy process (AHP) and VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR). The first phase of the study involves using the 5s methodology as a pre-assessment on the general status of the laboratory, where a form with 29 audit questions was given to the laboratory personnel to explore potential safety hazards. Next, the risk assessment was evaluated using FMEA to obtain a risk priority number (RPN). However, due to the limitation of classical FMEA, [17] combines FMEA, IT2FSs AHP and VIKOR in three steps. The first step involves identifying and evaluating failure modes. Next, the risk score was calculated, and IT2AHP is applied to assess failure modes. The final step in this approach was risk prioritization and potential control measures.

[12] conducted the chemical risk assessment in a chemical laboratory using three different techniques: Chem-SAM, University of Wollingong (UOW) risk assessment, and semi-quantitative risk assessment method (SQRA) method. The Chem-SAM model requires four steps: defining the chemical assets, defining the potential adversaries, calculating the chemical security risk, and determining risk acceptability. Whereas the UOW method involves eight steps: identifying name and location of the experiment, description of task/guidelines, hazard identification (equipment used and experimental design), hazard identification (material), control adopted for risk minimization, further risk control measure, risk matrix and conclusion of risk assessment. In SQRA, the risk of chemical exposure is calculated using hazard and exposure rating. The three methods were compared, and the results show a significant difference between SQRA and UOW but not with Chem-SAM. Chem-SAM

provides a systematic and replicable assessment method that is simple with no cost that helps to enhance risk management in a chemical laboratory [12].

A risk assessment of gas leakage from school laboratories has been conducted by [18] using BN. Many researchers have employed BN in risk assessment to overcome the static nature and ineffectiveness of conventional qualitative risk assessment such as fault tree and bowtie diagram in dealing with uncertainty [22]. The factors affecting the probabilities and consequences of gas leaks in school laboratories were analyzed based on expert experience, Dempster-Shafer theory, field investigation and case study. The study identified how factors such as environment, personnel behavior, equipment and safety management affect the probability of gas leakage, effect and consequences of the accident, which in turn help improve the safety management of gas in the laboratory.

Risk assessment in academic laboratories in the west of Iran has been conducted using CHRA and (RSLs) by [15], and a comparison was made between these two methods. The RSLs is a precise method that does not include personal judgment. In contrast, CHRA is a more straightforward method for wider chemicals that categorize risk with fewer parameters than RSIs and have personal judgment. The risk assessment using these methods identified chemicals of concern, occupation, and areas with higher risk. Findings show that these two methods is incompatible; however, they can complement each other for more accuracy.

MICE, a safety management program, has been adopted in academic surroundings to assess the risk in chemical laboratories related to chemicals, strong magnetic fields, and nanoparticles by [20]. The hazard in the laboratory was identified using Assessment and Classification of Hazards in Laboratories (ACHiL) and classified according to a four-level scale to prioritize further risk analysis. Management of chemicals, strong magnetic field, and nanomaterial were discussed to address safety hazards in the academic environment. [21] conducted hazard identification, risk management and incident analysis using the bowtie method in a laboratory setting. The bowtie methodology may assist universities in improving how they handle laboratory risks. It also provides an organized way of identifying essential safety barriers and controls, allowing for more effective monitoring of their strengths and conditions to prevent barrier degradation.

3.3 Hazard Identification

The first step in the risk assessment process is to identify a hazard. Various method has been employed to identify hazards in the academic laboratory such as using a checklist, workplace inspection, interview session with laboratory users, 5s and safety audits. For hazards identified in the academic laboratory, 54% of the publication discussed specific hazards (chemical hazards) while 46% on the non-specified hazard, as illustrated in Figure 3. Most of the hazard discussed was chemical hazard due to the hazardous nature of the chemical, the usage of chemical to conduct experiments in the laboratory, and the type of laboratory assessed mostly chemical laboratory. Other hazards discussed in the publication are physical, electrical, biological, ergonomic, and psychological hazards. Tables 3 and 4 summarizes the type of hazard discussed in the journal.
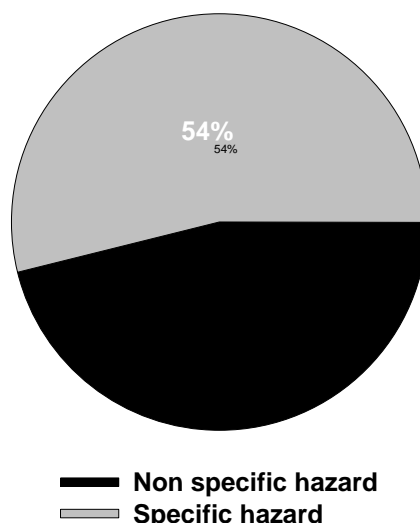
Fig.3. Type of Hazard Discussed

Table 4
Type of Hazard Identified

Article	Hazard						
	Chemical	Physical	Electrical	Biological	Psychological	Ergonomic	Mechanical
[17]	√	√	√	-	√	√	-
[12]	√	-	-	-	-	-	-
[13]	√	√	√	√	-	-	-
[14]	√	√	-	√	√	√	-
[3]	√	-	-	-	-	-	-
[8][9]	√	-	-	-	-	-	-
[18]	√	-	-	-	-	-	-
[15]	√	-	-	-	-	-	-
[19]	√	√	√	-	-	-	-
[20]	√	√	√	√	-	-	-
[21]	√	-	-	-	-	-	-
[16]	-	√	-	-	-	-	√

The main hazard is identified as chemical hazards. Exposure to chemical hazards can be in the form of gases, vapours, solids, and liquid. Laboratory users were exposed to chemical hazards from hazardous chemicals while conducting experiments with various experimental conditions. It is essential to identify chemical hazards to implement control measures, as chemical exposure can have immediate or long-term negative health consequences. Chemical hazards with high risk should be taken seriously to prevent a severe accident from happening. Electrical hazard usually arises from equipment where electric shock could occur while connecting the cable of the equipment to the socket. However, most electrical hazards are considered low risk because the current control measures effectively lower the risk. Physical hazards are hazards related to the environment of the work area. It includes exposure to heat, cold, noise, radiation, and magnetic field. The use of equipment that may cause fire and explosion, work area conditions that may cause slip or fall, injuries due to sharp objects are the commons physical hazards in the workplace. The risk of these physical hazards varies from low risk to very high risk.

Laboratory workers are also exposed to psychological hazards due to work stress that may lead to fatigue. The work stress may be related to workload, inflexible work schedule, inadequate equipment, poor communication and low support from the employer. Ergonomic hazards from an awkward working position lead to musculoskeletal disorder and muscle strain. Apart, laboratory users may also be exposed to biological hazards while dealing with biological specimens, leading to bacterial infection, disease transmission, and skin infection. Mechanical hazards were mainly observed in engineering laboratories where users deal with heavy-duty machinery that may cause injuries from hand-caught in machines, fracture, entrapment, crushing and cuts. All of these hazards should be appropriately managed to create a safe workplace in academic laboratories. The description of each of the hazards identified is listed in Table 5.

Table 5
Description of Hazard Identified

Hazard	Description	Reference
Chemical	Fire and explosion arising from uncontrolled chemical interactions, the use of hazardous chemical	[17]
	Exposure to a high concentration of acids and bases	[12]
	Exposure to formaldehyde used in cadaver handling, skin and eye irritation from alcohol and glycerin	[14]
	Exposure to chemical from chemical synthesis. (hazard derived from the information on physical, chemical, toxicological and exposure characteristic of a chemical.	[3][8][9]
	Exposure to chemical. Hazard identified based on thirty-three parameters of the hazardous properties of the chemical and operational condition.	[8][9]
	Gas leakage (Natural gas,methane, hydrogen silane, formaldehyde etc.)	[18]
	Exposure to chemical determined based on route of exposure, frequency duration rating and magnitude rating.	[15]
	Chemical inhalation, chemical ingestion, skin irritation,	[19]
	Hazardous chemical, flammable gas, toxic gas, nanoparticle, inert gas,	[20]
	Energetic Material	[21]
Electrical	Electric shock, short circuit, electrostatic discharge	[17]
	Electrical shock	[13]
	Electric shock from BOD reactor	[19]
	Electrical power	[20]
Physical	Burn, exposure to radiation, heat/cold, slip/trip, noise	[17]
	Heat from heating devices, fire and explosion from LPG, burn due to hot oil/product/surfaces, cuts from knife	[13]
	Finger injuries due to sharp object, blisters from hot water, sharp injuries from laboratory glassware, fire	[14]
	Cuts from broken glassware, heat exposure from the use of oven and soldering iron, slip/fall, fire/explosion from Atomic Absorption Spectroscopy	[19]
	Hot environment, cold environment, laser, cryogenic, ionizing radiation, explosive, magnetic field, environmental hazard	[20]
	noise, exposed to aluminum smelting heat, stove explosion, fire,	[16]

	smoke from smelting process, exposure to hot aluminum, eye exposure to spark	
Psychological	Fatigue	[17]
	Inconvenience and scare/stress from cadavers shaping and maintenance	[14]
Ergonomic	Muscle Strain	[17]
	Musculoskeletal disorders from sitting position, eye fatigue	[14]
Biological	Food contamination, bacterial infection, contaminated human droplets.	[13]
	Skin infection by Candida sp. and Epidemophyton sp. Transmission of disease from cadavers.	[14]
	Microorganism	[20]
Mechanical	Hands exposed to stirring machine, hands exposed to grinding machine, fall of aluminum on feet	[16]

3.4 Control Measure

Once risk has been identified, appropriate control measures must be taken according to the control hierarchy to mitigate the risk and prevent accidents. The control measures taken vary depending on the hazard encountered but were based on the control hierarchy to determine a feasible and effective control solution. The first line of control measures involves the elimination of the hazards or substitution followed by engineering controls, administrative control, and the use of personal protective equipment. A combination of different control measures may be required to manage the hazards efficiently. Most of the papers cited used at least more than one control measure to overcome the risk. The most common control measure applied is the combination of engineering, administration, and PPE, as tabulated in Table 3.

While elimination and substitution are the most efficient at minimizing hazards, they are also the most difficult to apply in an existing process since they may necessitate changes to the current procedure and equipment. Thus, the next best approach is to use engineering control. Engineering control protects workers from the hazardous situation by creating a barrier to the hazards, which can be done through physical modification to a process or equipment and installation of equipment to prevent a dangerous situation[23]

The most common engineering control applied in the academic laboratory is installing and improving local exhaust ventilation (LEV).[17],[12],[14], [18], [15],[16] applied the use of LEV as one of the control measures to overcome the hazard identified related to hazardous substances. LEV will provide a very efficient way of managing exposures to airborne contaminants such as pathogens, dust, fumes, mist, vapour and gases via inhalation, thus help to protect laboratory users from hazardous substances. It is crucial to ensure that the LEV must be carefully designed and built and appropriately used and maintained for the system to be effective. Other engineering controls applied are maintenance of laboratory equipment as discussed by [17] and [16]. The laboratory equipment needs to be appropriately used and well-maintained, as many laboratory accidents are caused by improper use and maintenance, which is not performed correctly. The maintenance of the equipment help to ensure the equipment is in good working condition and prevent the unnecessary hazard.

Administrative control is applied in the workplace to lessen and limit exposure to hazard. The enforcement of administrative control aid in improving safety in the academic laboratory by implementing training, safety procedure, policy or shift design that helps reduce the risk of a hazard.

The training was included as one of the administrative control in the articles discussed. The most frequent training organized in the academic laboratory is safety training, equipment usage training and emergency response and preparedness training. The purpose of this training is to equip laboratory staff with appropriate knowledge in identifying safety hazards and addressing them. Refresher training is needed to enhance, update and broaden the knowledge and skill obtained during the initial training. [15] suggest refresher training for laboratory staff every two years. On top of that, safety briefings were also suggested as an administrative control measure by [13], [24], [16]. Safety briefing aid in increasing staff awareness on the safety issue and could be done as a daily, weekly, or monthly briefing.

Other administrative controls listed in table 3 are preparing standard operating procedure (SOP), implementing buddy systems, preparing the chemical database, workplace inspections, marking work areas, and providing emergency equipment such as safety shower, eyewash, and first aid kit. The SOP usually contains information on working safely with hazardous chemicals or conducting experiments using hazardous equipment. SOP helps promote a safe work environment as it delivers risks associated with an activity and how to handle them to ensure operations are carried out correctly and safely. Workplace inspection may also aid in ensuring safety in the laboratory. It is carried out by carefully examining the work area to identify any potential hazards that may cause injuries. Workplace inspections are vital in actively monitoring the organization's safety and its adherence to safety standards.

The last line of control measure to protect against worker's injury and illness is personal protective equipment (PPE). PPE needs to be readily available in the laboratory for laboratory users. It is essential to identify the right PPE depending on the hazard with the most commonly used PPE are gloves, safety glasses and shoes, earplugs or muffs, respirators, and lab coats. PPE training needs to be conducted to provide correct information and instruction on PPE usage, maintenance, and disposal. Refresher training may be required from time to time. Continuous inspection of the PPE is also needed to identify damaged or malfunctioning PPE before usage.

4. Conclusion

Limited research has been conducted on hazard identification, risk assessment, and risk control in academic laboratories. Lack of risk assessment applied in academic laboratories imposes a severe threat in academia due to the continuous growth of research, resulting in a lack of well-defined methods. The first step requires identifying the potential hazard by employing hazard review based on readily available data or information. The second stage requires executing a formal risk assessment and the final stage involves implementing risk mitigation procedures. In future work, a simple, fast, low cost and efficient risk assessment is needed to aid academic laboratories in further improving laboratory risk management. A combination of qualitative and quantitative risk assessment methods may be required to enhance the risk assessment process by utilizing the positive aspect of both methods. The self-evaluation for hazard identification should be minimized as it could be a source of bias. The risk assessment provides systematic efforts to address flaws that could result in a laboratory accident. With the emerging Industry Revolution 4.0 (IR 4.0) on big data analytics, it would be great to have an online risk assessment to effectively communicate the risk to laboratory users to eliminate or reduce accident cases in the laboratory with the hope to aid academic laboratories in their effort to improve safety and manage the risk of accident.

Acknowledgement

References

[1]   T.W. Ragsdale, B.L. Hankinson, Laboratory Safety Program at, Chem. Heal. Saf. 7 (2000) 10–13.

[2]   P. Kesedaran, K. Makmal, K. Kes, Assessing Awareness on Laboratory Safety : A Case Study in Pahang , Malaysia, J. Pendidik. Malaysia. 43 (2018) 73–80.

[3]   D.J. Leggett, Identifying hazards in the chemical research laboratory, Process Saf. Prog. (2012).

[4]   J.H. Gibson, I. Schröder, N.L. Wayne, A research university's rapid response to a fatal chemistry accident: Safety changes and outcomes, J. Chem. Heal. Saf. 21 (2014) 18–26.

[5]   M. Chen, Y. Wu, K. Wang, H. Guo, W. Ke, An explosion accident analysis of the laboratory in university, Process Saf. Prog. 39 (2020) 1–10.

[6]   A.D. Ménard, J.F. Trant, A review and critique of academic lab safety research, Nat. Chem. 12 (2020) 17–25.

[7]   T. Su, I. Hsu, Perception towards chemical labeling for college students in Taiwan using Globally Harmonized System, 46 (2008) 1385–1392.

[8]   D.J. Leggett, Lab-HIRA : Hazard identification and risk analysis for the chemical research laboratory : Part 1 . Preliminary hazard evaluation, (2012) 9–24.

[9]   D.J. Leggett, Lab-HIRA : Hazard identification and risk analysis for the chemical Part 2 . Risk analysis of laboratory operations, (2012).

[10]   Y. Xiao, M. Watson, Guidance on Conducting a Systematic Literature Review, J. Plan. Educ. Res. 39 (2019) 93–112.

[11]   H.A. Mohamed Shaffril, N. Ahmad, S.F. Samsuddin, A.A. Samah, M.E. Hamdan, Systematic literature review on adaptation towards climate change impacts among indigenous people in the Asia Pacific regions, J. Clean. Prod. 258 (2020) 120595.

[12]   S. Karimi Zeverdegani, S. Barakat, M. Yazdi, Chemical risk assessment in a chemical laboratory based on three different techniques, J. Occup. Heal. Epidemiol. 5 (2016) 168–175.

[13]   A.A. Athqiya, D.N. Haqi, P.A. Alayyannur, I. Paskarini, F.M. Sugiharto, Hazard identification, risk assessment, and determining controls in laboratories, Indian J. Public Heal. Res. Dev. 10 (2019) 877–883.

[14]   R. Fauziah, P.A. Alayyannur, D.N. Haqi, S. Hidayat, W.F. Alfin, Hazard identification, risk assessment, and determining control (HIRADC) method in a university laboratory in Surabaya, Indonesia, Indian J. Forensic Med. Toxicol. 14 (2020) 380–385.

[15]   E. Taheri, F. Mollabahrami, M. Farokhzad, F. Ghasemi, M.J. Assari, Risk assessment in academic laboratories in the west of Iran: compare the CHRA and the RSLs methods, Int. J. Environ. Health Res. 30 (2020) 198–211.

[16]   Buchari, N. Matondang, N. Sembiring, Work environment engineering using HIRARC and 5S method, AIP Conf. Proc. 1977 (2018).

[17]   Y. Ozdemir, M. Gul, E. Celik, Assessment of occupational hazards and associated risks in fuzzy environment: A case study of a university chemical laboratory, Hum. Ecol. Risk Assess. 23 (2017) 895–924.

[18]   X. Zhang, X. Hu, Y. Bai, J. Wu, Risk assessment of gas leakage from school laboratories based on the Bayesian network, Int. J. Environ. Res. Public Health. 17 (2020).

[19]   M.A. Budihardjo, F.I. Muhammad, A.R. Rizaldianto, Application of Risk Identification, Risk Analysis, and Risk Assessment in the University Laboratory, IOP Conf. Ser. Mater. Sci. Eng. 598 (2019).

[20]   J.L. Marendaz, K. Friedrich, T. Meyer, Safety management and risk assessment in chemical laboratories, Chimia (Aarau). 65 (2011) 734–737.

[21]   M.B. Mulcahy, C. Boylan, S. Sigmann, R. Stuart, Using bowtie methodology to support laboratory hazard identification, risk management, and incident analysis, J. Chem. Heal. Saf. 24 (2017) 14–20.

[22]   E. Zarei, N. Khakzad, V. Cozzani, G. Reniers, Safety analysis of process systems using Fuzzy Bayesian Network (FBN), J. Loss Prev. Process Ind. 57 (2019) 7–16.

[23]   William H Bullock; Joselito S Ignacio; John R Mulhausen, A Strategy for Assessing and Managing Occupational Exposures, 4th edition, 4th editio, AIHA Press, Fairfax, 2015.

[24]   R. Fauziah, P.A. Alayyannur, D.N. Haqi, S. Hidayat, W.F. Alfin, Hazard identification, risk assessment, and determining control (HIRADC) method in a university laboratory in Surabaya, Indonesia, Indian J. Forensic Med. Toxicol. 14 (2020) 380–385.