

Be safe at laboratory: basic knowledge to develop self-awareness

Abstract

Laboratory practice is one of the most effective tools for students to learn science. However, the laboratory environment involves several hazards, such as the risk of spills, burns, and fires. In this context, self-awareness is the best tool to ensure safety in the laboratory. This includes following safety rules and properly managing the experiment to be conducted, as it is essential to understand all requirements beforehand. In general, several activities must be reviewed before starting laboratory work. This article proposes using a checklist to address all these activities. The use and communication of the near-miss incidents play a crucial role in safety. Additionally, items related to equipment use, safety concerns such as electrostatic discharge, fume hoods, and certain chemical reactions will be presented.

Keywords: safety measures, laboratory, check list, facilities, near miss report

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Introduction

Laboratory practice is one of the most effective ways for students to learn science.¹ Whether in biology, microbiology, physics, or chemistry, hands-on experience enhances understanding and reinforces theoretical knowledge. In the case of chemistry laboratories, special precautions are essential due to the handling of various reagents, solvents, and specialized equipment. Before entering to the laboratory, especially for the first time, it is crucial for students to understand basic safety protocols. Ensuring student safety is the top priority for all the teachers and laboratory responsible. In the first paragraphs of the article, it is outlined essential safety guidelines that every student must follow before and during laboratory sessions. Moreover, a checklist of activities will be proposed to help prepare tasks before working in the laboratory. It serves as an introductory reference to help students develop safe laboratory habits from the beginning of the training. Last paragraphs are devoted to important safety topics intended for laboratory supervisors. It emphasizes the minimum safety standards that must be upheld to maintain a secure and efficient working environment.

Real-life laboratory accidents: Lessons in safety

In 2008, a tragic accident occurred in the chemistry-biochemistry laboratory at the University of California. A young student was transferring tert-butyl-lithium from a bottle into a syringe when the plunger unexpectedly dislodged from the syringe barrel. The highly reactive chemical splashed onto her clothing and ignited upon contact with air, setting her on fire. She suffered severe burns on her hands, arms, and upper torso, covering approximately 40% of her body. Despite receiving medical treatment, the student tragically passed away several days later. Tert-butyl lithium is a pyrophoric organometallic reagent, meaning it ignites spontaneously when exposed to air. Working with such hazardous substances requires strict safety protocols, including the use of appropriate fire extinguishers, flame-resistant lab coats, and thorough training in handling dangerous chemicals. Unfortunately, it appears that these critical safety measures were not adequately followed in this case.²

Another serious incident occurred in 2010 at Texas Tech University. Two students were conducting experiments involving explosive compounds. After performing small-scale trials, they

attempted to scale up the experiment using a similar procedure. During the mixing of the main compound with a solvent, an explosion occurred. One of the students suffered severe injuries to his hand and face. Investigations into both incidents were conducted and published by the U.S. Chemical Safety and Hazard Investigation Board (CSB).³

These tragic events underscore the vital importance of proper training, adherence to safety protocols, and the consistent use of personal protective equipment (PPE). The following sections will further explore these essential safety measures and provide guidance for both students and laboratory supervisors to help prevent and minimize such accidents in the future.

Basic safety measures before and during laboratory work

Working in a laboratory requires careful preparation and strict adherence to safety protocols to prevent accidents and ensure a safe environment for everyone. Before beginning any laboratory activity, it is essential to review the experimental procedure thoroughly and prepare all necessary materials and equipment. This preparation helps minimize risks and ensures that the experiment proceeds smoothly. Here are some fundamental safety measures to keep in mind while working in a laboratory: cleanliness, read and understand the experiment, read the reagents material safety data sheets, prepare the safety protection equipment, set up the material to be used, review the facilities like the fume hoods, know the safety measures, have a contingency plan and do a timing of the experiment among others (Figure 1).

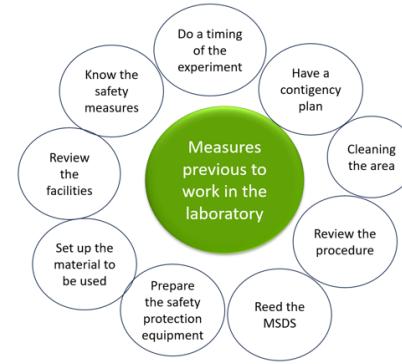


Figure 1 Basic safety measures in the laboratory.

The Importance of cleanliness in the laboratory

Maintaining a clean laboratory and especially a tidy work area is essential for ensuring the safety of students and staff. A cluttered workspace increases the risk of accidents due to unexpected movements, spills, or interference with equipment. Imagine conducting multiple experiments involving flammable compounds in a confined space filled with unnecessary materials. Such conditions significantly raise the likelihood of incidents, especially when working with volatile substances. Cleanliness is not only about safety; it also plays a crucial role in the accuracy and reliability of experimental results. A clean environment minimizes the risk of contamination, which can otherwise compromise data and lead to inconsistent or invalid outcomes. Moreover, regular cleaning helps extend the lifespan of laboratory equipment. Spills of reagents or solvents can cause corrosion or damage to sensitive instruments, leading to costly repairs or replacements. By keeping the workspace clean and organized, students and researchers contribute to a safer, more efficient, and more productive laboratory environment. An interesting article about the importance of cleanliness has been reported recently (Figure 2).⁴

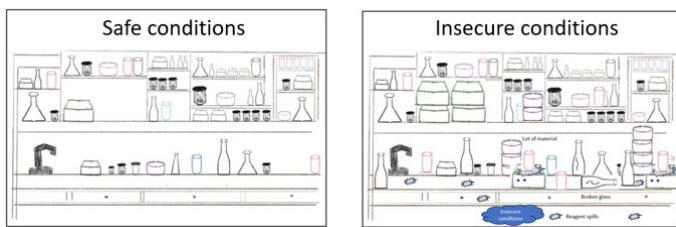


Figure 2 The importance of cleanliness in the laboratory.

The Importance of reading the experiment before starting

Reading the experiment thoroughly before beginning any laboratory work offers several key advantages that contribute to both safety and efficiency:

- Understanding the objective: First and foremost, reading the experiment helps students understand the purpose of the activity. Knowing *why* the experiment is being conducted enhances engagement and promotes critical thinking.
- Identifying potential hazards: Reviewing the procedure in advance allows students to recognize the risks associated with specific reagents, solvents, and reaction conditions. This awareness is essential for implementing the appropriate safety measures and using the correct personal protective equipment (PPE).
- Proper material preparation: A careful reading ensures that all necessary materials and equipment are prepared before starting. This includes steps such as drying glassware, preparing quenching solutions, and setting up apparatus correctly.
- Saving time and avoiding mistakes: Being familiar with the procedure helps avoid delays caused by missing materials or misunderstood steps. It allows the experiment to proceed smoothly and efficiently, reducing the likelihood of errors.

In summary, taking the time to read and understand the experiment beforehand is a simple yet powerful practice that enhances safety, accuracy, and productivity in the laboratory.

The role of safety data sheets (SDS) in laboratory safety

Safety Data Sheets (SDS), formerly known as Material Safety Data Sheets (MSDS), are essential documents that provide comprehensive information about chemical substances such as reagents, solvents, and intermediates. These documents are of critical importance for understanding the potential hazards associated with each material and for ensuring safe handling in the laboratory.

An SDS typically includes details on chemical properties and composition, health and environmental hazards, safe handling and storage guidelines, required personal protective equipment (PPE), first aid and emergency procedures, spill and disposal recommendations. Although reading SDS documents may seem tedious, it is a crucial step in laboratory preparation. As highlighted in the tragic incidents discussed earlier in this document, a lack of awareness about chemical hazards can lead to severe injuries or even fatalities. Familiarizing oneself with the SDS before using any chemical can significantly reduce the risk of accidents and ensure a safer working environment for everyone involved.

Preparing and using personal protective equipment (PPE)

After reviewing the Safety Data Sheets (SDS) for the chemicals involved in an experiment, the next essential step is to prepare and wear the appropriate personal protective equipment (PPE). PPE serves as the first line of defense against potential hazards such as chemical spills, splashes, reaction projections, and other unexpected incidents. Standard PPE for laboratory work typically includes. Safety goggles or glasses to protect the eyes from chemical splashes or flying particles. Lab coats to shield the skin and clothing from spills and contamination. Gloves suitable for the chemicals being handled (e.g., nitrile, latex, or neoprene). Closed-toe shoes to protect the feet from spills or dropped equipment. Wearing proper PPE not only ensures physical protection but also fosters a sense of security and professionalism among students. When students feel safe, they can focus more effectively on the experiment itself rather than worrying about potential hazards. This improves both learning outcomes and overall laboratory efficiency (Figure 3).

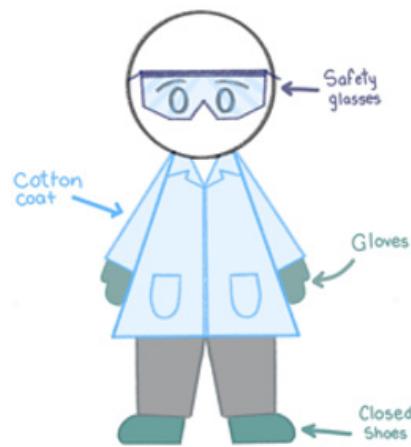


Figure 3 Personal protective equipment.

Reviewing laboratory facilities before starting work

Before beginning any laboratory activity, it is essential to inspect the laboratory facilities and equipment. This step is crucial for minimizing the risk of accidents and ensuring that all systems are functioning properly. A thorough review helps identify potential hazards, ensures the correct handling of chemicals, and prepares students for emergency situations.

Some key items to inspect include:

- a. Fume hood: Verify that the fume hood has been recently calibrated. Ensure the airflow is functioning correctly to safely remove hazardous vapors. Check that the protective sash (glass shield) moves smoothly and can be positioned properly for maximum protection.
- b. Vacuum pumps: Inspect for any visible damage or leaks, confirm that all connections are secure and that the pump is operating within safe parameters. Confirm if the pump has enough oil (if applies).
- c. Heating devices (e.g., hot plates, heating mantles): Check that all electrical cords and plugs are intact and undamaged. Ensure the devices are functioning correctly and placed on stable, heat-resistant surfaces. Never leave heating equipment unattended while in use.
- d. General electrical connections: Inspect power outlets and extension cords for signs of wear or damage. Avoid overloading circuits and ensure that all equipment is properly grounded. By conducting a careful review of the laboratory setup, students and instructors can prevent many common accidents and create a safer, more controlled environment for scientific exploration.

Golden rules for laboratory safety

To maintain a safe and efficient laboratory environment, students must always follow these fundamental safety rules:

- a) Never eat or drink in the laboratory: Consuming food or beverages in the lab can lead to accidental ingestion of toxic substances, resulting in serious health risks.
- b) Never work alone. Always ensure that at least one other person is present. In case of an emergency, a colleague can provide immediate assistance or call for help.
- c) Wash your hands after working in the lab: This simple habit helps prevent chemical contamination and accidental ingestion of hazardous substances.
- d) Use the fume hood during experiments: All volatile or hazardous reagents must be handled inside a properly functioning fume hood to avoid inhalation of toxic vapors.
- e) Handle glassware with care: Never force glass joints together. Use appropriate lubricants to ensure smooth connections and prevent breakage.
- f) Never smell chemicals directly: If it is necessary to detect an odor, ask an experienced instructor to demonstrate the proper wafting technique.
- g) Label all glassware clearly: Proper labeling prevents dangerous mix-ups. For example, mistaking sulfuric acid for water during cleaning could cause a serious chemical spill.

- h) Ask for help when unsure: If you are uncertain about how to perform a task or use equipment, always ask the instructor or lab supervisor for guidance.
- i) Know the location of emergency equipment: Be familiar with the locations of eyewash stations, safety showers, fire extinguishers, first aid kits, and emergency exits.
- j) Know the emergency exit routes: Understand how to quickly and safely evacuate the lab and building in case of an emergency.
- k) Check the emergency kit: Ensure that the emergency kit is complete and contains all necessary supplies.
- l) Report all accidents immediately: Notify your instructor or supervisor of any spills, injuries, or unsafe conditions as soon as they occur.
- m) Respond to spills properly: If a chemical spills on your skin, rinse the affected area immediately with plenty of water and seek assistance.
- n) Dispose of broken glass correctly: Place broken glass in designated containers to prevent injury and contamination. Never use a glassware broken.
- o) Follow proper chemical waste disposal procedures: Never pour chemicals down the sink unless specifically instructed. Use the appropriate waste containers for disposal.
- p) Clean your workspace after the experiment: Wipe down benches and return materials to their proper places to maintain a safe and organized lab environment.

Being prepared for emergencies in the laboratory

While it is primarily the responsibility of the person in charge of the laboratory to manage safety protocols, it is equally important for students to be aware of how to respond in case of an emergency. There is a well-known saying in safety **“It is better to be prepared for an event that never happens than to be unprepared when it does.”** Understanding how to act in emergency situations can make a critical difference. Here are some common incidents and the recommended responses:

Common laboratory emergencies and how to respond

- a. Spill of a Reagent: Alert others in the lab immediately. Avoid contact with the spilled substance. Use appropriate spill kits to contain and clean the spill. Ventilate the area if fumes are present. Report the incident to the lab supervisor.
- b. Injuries from Broken Glass: Do not touch broken glass with bare hands. Use tongs or a dustpan and brush to collect the pieces. Dispose of broken glass in designated containers. If injured, wash the wound with water and seek first aid.
- c. Burns from acids or bases: Immediately rinse the affected area with plenty of water for at least 15 minutes. Remove contaminated clothing carefully. Seek medical attention and report the incident.
- d. Spill of Flammable Reagents: Eliminate all ignition sources immediately. Use appropriate absorbent materials and spill kits. Ensure proper ventilation. Do not attempt to clean large spills alone notify the supervisor.

e. Spill of Solvents: Many solvents are volatile and flammable. Use the fume hood if possible. Clean up with appropriate absorbents and dispose of waste properly. Report the spill and monitor for symptoms of exposure.

Essential emergency preparedness in the laboratory

Being prepared for emergencies is a fundamental aspect of laboratory safety. While the primary responsibility lies with the person in charge of the lab, all students and staff should be familiar with emergency protocols. Here are key elements to review before starting any experiment:

Fire safety

- Know the location of emergency exits: In case of fire or other emergencies, quick evacuation is critical. Always identify the nearest exit before beginning work. Keep exit paths clear: Never block access to exits with equipment or materials.
- Fire Extinguishers: Locate extinguishers before starting to work in the lab. Know where the fire extinguishers are and ensure they are accessible. Move an extinguisher closer if needed. For high-risk experiments (e.g., involving pyrophoric reagents like organometallics or palladium compounds), place an extinguisher near the fume hood. Know how to use it. Familiarize yourself with the PASS method (Pull, Aim, Squeeze, Sweep).
- First Aid Kit: Ensure the lab has a stocked first aid kit with basic supplies such as: alcohol or antiseptic wipes, band-aids and gauze, burn cream, gloves, eye wash solution.
- Emergency Protocols: Establish clear procedures for common incidents such as: chemical spills, fires, burns or injuries, power outages, equipment malfunctions
- Display protocols visibly in the lab for quick reference.
- Conduct regular drills to ensure everyone knows how to respond.

Planning the experiment: a critical step for safety and success

One of the most important steps before entering the laboratory is careful planning of the experiment. This includes outlining the entire process from the reaction setup to the isolation and final analysis of the products. Proper planning not only ensures efficiency but also significantly reduces the risk of accidents. Many laboratory incidents occur because students underestimate the time required for an experiment or attempt to rush the process. For example, increasing the reaction temperature from the recommended 50 °C to 80 °C to speed up the reaction can lead to runaway reactions, which may result in dangerous situations such as fires or explosions. By planning the experiment in advance, students can: allocate sufficient time for each step, avoiding the temptation to rush, identify critical points in the procedure that require extra caution, prepare all necessary materials and safety equipment ahead of time, anticipate potential risks and plan appropriate safety measures. In summary, planning helps save time and resources, improves the quality of results, and most importantly, helps prevent accidents.

The value of using a laboratory safety checklist

To ensure safety in the laboratory, it is essential to plan and follow each activity carefully. Without proper planning, students are exposed to numerous risks that could lead to accidents or injuries. One of the most effective tools to support safe laboratory practices is the checklist.⁴ A checklist helps control multiple variables that are often difficult to track during an experiment. It serves as a step-by-step guide to ensure that all safety measures are in place before, during, and after the experiment. Items on a safety checklist typically include verification of personal protective equipment (PPE), review of the experimental procedure, inspection of equipment and facilities, availability of emergency equipment (fire extinguisher, first aid kit, spill kit), proper labeling and storage of chemicals, waste disposal procedures, cleanup and decontamination steps. This is a basic proposal, and with time and experience, students should adapt and improve their checklists to suit specific experiments and laboratory environments. Additionally, consulting examples from other institutions or safety manuals can provide valuable insights and help refine the checklist further.⁵ The check list is show in the (Table 1).

Table 1 Basic check list for students before entering to laboratory.

Basic checklist previous to work in the laboratory			
Activity	Responsible	Status	Comments
Review the basis of the experiment			
Read the reagents material safety data sheets			
Prepare the safety protection equipment			
Cleaning the working area			
Prepare the safety protection equipment			
Set up the material to be used			
Review the facilities like the fume hoods			
Know the safety measures			
Do a timing of the experiment			
Have a colleague to work in laboratory			
Notify the responsible			
Have the emergency phone number			
Review the safety kit			
Review the contingency plan			
Cleaning working area			
Store the products			
Store the reagents			

- Collect the residues and deliver to the responsible
- Switch off the equipment
- Other

Key responsibilities and safety oversight in the laboratory

This section is designed to deepen understanding of critical safety topics that, while primarily the responsibility of the laboratory supervisor or person in charge, should also be familiar to students. Awareness of these responsibilities helps students recognize whether proper safety protocols are being followed and encourages a shared culture of accountability in the lab.

As it was already mentioned: "It is better to be prepared for something that never happens than to be unprepared when it does." Students should be aware of the following key areas, even if they are not directly responsible for them:

Key areas of oversight and student awareness

- a. Spill management: Understand the procedures for handling chemical spills, including the location and use of spill kits, and the importance of immediate reporting.
- b. Glassware injuries: Know how to respond to cuts or injuries caused by broken glass, and where to find first aid supplies.
- c. Chemical burns (e.g., from acids or bases): Be familiar with emergency rinsing procedures, including the use of safety showers and eye wash stations.
- d. Reagent and solvent spills: Recognize the difference between types of spills (e.g., corrosive vs. flammable) and the appropriate containment and cleanup methods.
- e. Fire safety and evacuation: Know the location of fire extinguishers and emergency exits. In high-risk experiments (e.g., involving pyrophoric reagents like organometallics or palladium compounds), ensure extinguishers are nearby and accessible.
- f. First aid kit availability: Confirm that the lab is equipped with a stocked first aid kit containing basic items such as antiseptics, bandages, gloves, and burn treatment supplies.
- g. Emergency protocols: Protocols for common incidents (e.g., chemical exposure, fire, equipment failure) should be clearly posted and reviewed regularly. Students should be familiar with these procedures and participate in safety drills when possible.

Fume hoods: essential equipment for laboratory safety

Fume hoods are one of the primary lines of defense for students in academic laboratories and for personnel in industrial or research facilities. Their main function is to extract harmful gases whether acidic, basic, or neutral produced by reagents or generated during chemical reactions. By continuously drawing air from the front opening and expelling it outside, fume hoods help maintain a safe breathing environment and reduce the risk of exposure to toxic or flammable vapors.

Maintenance and functionality: As technical safety equipment, fume hoods must be included in a regular maintenance program to ensure they operate within the required performance parameters. Key aspects of maintenance include calibration of airflow to ensure proper ventilation. Inspection of the sash (protective glass window) to confirm

it moves smoothly and provides adequate shielding, verification of airflow alarms or indicators, if present, cleaning of internal surfaces to prevent buildup of residues that could lead to contamination or fire hazards. Proper installation is also critical. The ducting system must be designed to ensure efficient extraction, and the hood must be located away from high-traffic areas to avoid airflow disruption.

Common misuses and issues: As noted by Richard Palluzzi,⁶ several common problems can compromise the effectiveness of fume hoods:

Excessive storage of reagents inside the hood: While it may seem convenient, storing too many chemicals inside the hood can obstruct airflow and reduce its effectiveness.

Storing equipment inside the hood: Using the hood as a storage cabinet for glassware or instruments is a common mistake that limits workspace and airflow.

Improper use of the sash: Keeping the sash too high or fully open during experiments can reduce containment efficiency and increase exposure risk.

Additional Features. Modern fume hoods often include built-in utilities such as: water taps for cooling or cleaning, nitrogen or inert gas lines for blanketing sensitive reactions. Compressed air outlets for applications like chromatography, storage compartments, though these should not be used for long-term storage of volatile or odorous chemicals.

It's important to note that while some reagents with strong odors may be temporarily stored in the hood, this should not become a permanent practice. Proper chemical storage cabinets especially ventilated or flammable storage units should be used instead. The Lean Six sigma philosophy can help to maintain a good order in the fume hood.⁷ Finally, the requirement for fume hood has been published by the NTP (Figure 4).⁸

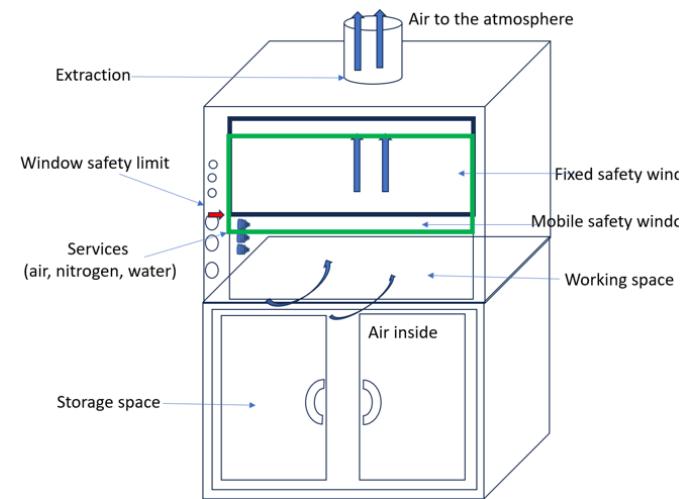


Figure 4 Basic parts of a fume hood.

Personal protective equipment (PPE): Your first line of defense

Personal Protective Equipment (PPE) is essential for safeguarding the body against chemical and physical hazards in the laboratory. Before

beginning any experiment, students must ensure they are equipped with the appropriate PPE for the specific tasks and materials involved. The main areas of the body that require protection include the eyes, face, torso, hands, and feet.

Eye protection: The purpose of glasses is preventing splashes of reagents, solvents, or reaction by-products from reaching the eyes. In the market there are several types of Safety goggles, face shields, or ergonomic safety glasses with side protection. The best practice is always wearing even for seemingly simple tasks.

Body protection: The lab coats protect the torso and arms from chemical splashes. There are different types of lab coats. Cotton lab coats are suitable for standard experiments and specialized coats for specific tasks e.g. resistant or aluminum-lined materials, are recommended for high-risk procedures (e.g., handling organometallics at scale). Important Note: Lab coats must always be fully buttoned. Leaving them open exposes the body to potential chemical contact.

Hand protection: Gloves are critical, as hands are the most exposed part of the body during lab work. There are several types of gloves for example. Nitrile gloves, suitable for general chemical handling and procedures like crystallization. Cryogenic gloves required for handling substances at very low temperatures (e.g., -70 °C). Neoprene gloves, recommended for working with strong acids or corrosive chemicals. Always match the glove type to the chemical hazard. Never reuse disposable gloves.

Foot protection: Footwear. Closed-toe shoes are mandatory. However, sports shoes are not recommended as they may not provide adequate protection. Consider using chemical-resistant or safety shoes, especially when working with heavy equipment or hazardous liquids.

Respiratory protection: For procedures that generate harmful dust, fumes, or vapors not fully contained by a fume hood. Equipment: Use appropriate respirators or masks with certified filters (e.g., organic vapor cartridges or particulate filters) based on the type of exposure. These PPE items (Figure 5) represent the basic protective gear required to ensure the safety of students and laboratory personnel. As experience grows, students should become more familiar with selecting and using PPE tailored to specific experimental conditions.



Figure 5 Basic laboratory personal protection equipment.

Cleanliness and order: a key to laboratory safety and efficiency

One of the most common root causes of laboratory accidents is poor cleanliness and disorganization in the work area. Maintaining a clean and orderly laboratory is not just about aesthetics it is a fundamental aspect of safety and operational efficiency.

Common issues due to lack of cleanliness: Used syringes left in the workspace, increasing the risk of accidental punctures or contamination. Dirty or unwashed laboratory glassware, which can lead to cross-contamination and inaccurate results. Dust accumulation in fume hoods, which can interfere with airflow and pose fire hazards. Excessive reagents and solvents cluttering the workspace, increasing the risk of spills or unintended reactions. Overcrowding with tools like tweezers, making it difficult to work safely and efficiently.

Benefits of a clean laboratory: Reduces the risk of accidents by eliminating unnecessary hazards. Improves experimental accuracy and repeatability by minimizing contamination. Extends the life of equipment by preventing damage from spills or residue. Promotes a professional and responsible lab culture.

Applying the 5S methodology in the lab

The 5S methodology from Lean Six Sigma⁹ is a powerful tool for improving workplace organization and cleanliness. It consists of five key steps:

1. Sort (Seiri): Remove unnecessary items from the workspace.
2. Set in Order (Seiton): Organize tools and materials so they are easy to find and use.
3. Shine (Seiso): Clean the workspace and equipment regularly.
4. Standardize (Seiketsu): Establish routines and standards for maintaining cleanliness and order.
5. Sustain (Shitsuke): Develop habits and discipline to maintain the improvements over time.

Implementing 5S in the laboratory can significantly enhance safety, reduce waste, and improve the overall quality of scientific work.

What is a safety data sheet (SDS)?

A Safety Data Sheet (SDS) is a standardized document created by manufacturers or suppliers of chemical substances such as reagents, solvents, or organic compounds to provide detailed information about the properties and hazards of those substances. These documents are essential for ensuring safe handling, storage, and disposal of chemicals in laboratories and workplaces. The term Material Safety Data Sheet (MSDS) was officially replaced by Safety Data Sheet (SDS) to align with the Globally Harmonized System (GHS) of Classification and Labelling of Chemicals, developed by the United Nations. This change was also adopted by OSHA (Occupational Safety and Health Administration) to standardize chemical safety information worldwide and improve clarity and consistency.¹⁰ As mentioned, Safety Data Sheets (SDS) are standardized documents that provide essential information about chemical substances. They are divided into 16 specific sections, as defined by the Globally Harmonized System (GHS) and adopted by OSHA. Here's a breakdown of each section:

The 16 Sections of a safety data sheet (SDS)

- a. Identification: Product name, manufacturer/supplier details, recommended uses, and emergency contact information.
- b. Hazard identification: Classification of the chemical, label elements (pictograms, signal words), and hazard statements.
- c. Composition/information on ingredients: Chemical identity, common names, CAS numbers, and concentration of ingredients.
- d. First-aid measures: Necessary first-aid steps for different types of exposure (inhalation, skin, eye, ingestion).
- e. Fire-fighting measures: Suitable extinguishing media, specific hazards from combustion, and protective equipment for firefighters.
- f. Accidental release measures: Procedures for containment, cleanup, and emergency response in case of spills or leaks.
- g. Handling and storage: Safe handling practices and storage conditions, including incompatibilities.
- h. Exposure controls/personal protection: Exposure limits, engineering controls, and recommended personal protective equipment (PPE).
- i. Physical and chemical properties: Appearance, odor, pH, melting/boiling point, flash point, solubility, etc.
- j. Stability and reactivity: Chemical stability, possible hazardous reactions, and incompatible materials.
- k. Toxicological Information: Health effects, symptoms of exposure, and toxicological data (e.g., LD50).
- l. Ecological information (non-mandatory for OSHA): Environmental impact, including aquatic toxicity and persistence.
- m. Disposal considerations (non-mandatory for OSHA): Guidelines for safe disposal of the chemical and its container.
- n. Transport information (non-mandatory for OSHA): UN number, transport hazard class, packing group, and special precautions.
- o. Regulatory information (non-mandatory for OSHA): Safety, health, and environmental regulations specific to the substance.
- p. Other information: Date of preparation or last revision, and any additional relevant information.

Even though the structure of SDS documents is intuitive, there are common issues in many workplaces that must be avoided to ensure safety and compliance:

Common SDS management issues to avoid: SDS Must Be Easily Accessible, all safety data sheets should be stored in a clearly marked, easily accessible location either in physical binders or digital formats. Every laboratory user must know where to find them in case of an emergency. SDS must be in the native language to ensure full comprehension, SDS documents must be available in the language spoken by the personnel using the chemicals (authors are from Mexico). Misunderstanding safety instructions due to language barriers can lead to serious accidents. SDS must be up to date outdated SDS documents may contain obsolete or missing safety information. It is essential to regularly review and update SDS files to reflect the most current data provided by manufacturers.

Electrostatic charges and flammable atmospheres: understanding the risks

In laboratory and industrial environments, electrostatic charges can accumulate on objects, equipment, and even people. If these charges are not properly discharged, they can create a spark, which becomes a serious hazard especially in the presence of flammable or explosive atmospheres. Static electricity can build up through friction or movement (e.g., walking on certain floors, handling plastic containers). Without proper grounding or discharge methods, this static can release as a spark. In environments with flammable vapors or dust, even a small spark can ignite a fire or cause an explosion. To initiate a fire, three elements must be present (fire triangle¹¹):

Fuel: A flammable substance (e.g., solvent vapors, gases, dust).

Oxidizer: Typically, oxygen in the air.

Ignition Source: Such as a spark from static electricity or faulty equipment.

To escalate a fire into an explosion (explosion pentagon¹²), two additional elements are required:

Dispersion: A fine distribution of flammable material (e.g., a dust cloud or vapor).

Confinement: An enclosed space that allows pressure to build up rapidly.

When all five elements are present, and the concentrations are within flammable or explosive limits, a fire or explosion can occur. The fire triangle and the explosion pentagon are showed in the (Figure 6).

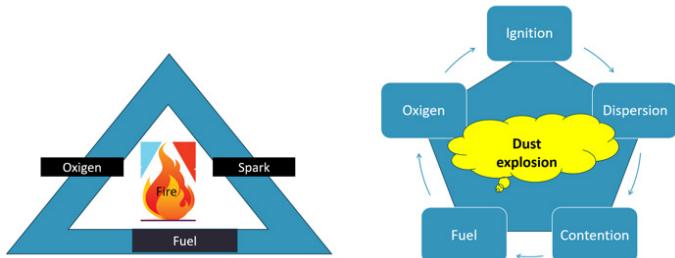


Figure 6 Component of the fire triangle and an explosion.

The critical role of sparks in fire and explosion prevention

As we previously pointed out, the most important element to control in the fire triangle is the ignition source, particularly sparks caused by electrostatic discharge (ED). While fuel (e.g., solvents, gases) and oxidizers (e.g., air or oxygen) are often unavoidable in laboratory settings, sparks can and must be prevented through proper safety measures. Why sparks are so dangerous? Electrostatic energy commonly known as static electricity is generated when two different materials come into contact and then separate, especially when one is a poor conductor (an insulator). This process, known as triboelectric charging,¹³ can lead to the accumulation of electrons on surfaces. If these charges are not safely discharged, they can suddenly release as a spark, which may ignite flammable vapors or dust.

From fire to explosion

As it was mentioned previously, a fire requires, fuel, oxidizer and an ignition source. When all these elements are present, and the

concentrations are within flammable or explosive limits, a catastrophic event can occur.

How to prevent sparks and electrostatic discharge: Use grounding wires and bonding straps to provide a path for static charges to dissipate safely. Avoid using synthetic clothing. Wear natural fibers like cotton, which are less likely to generate static. Use anti-static mats and wrist straps. Especially when working with flammable materials or sensitive electronics. Control humidity. Dry environments increase the risk of static buildup. Maintaining appropriate humidity levels can help reduce this risk. Use conductive containers. Avoid plastic or glass containers for transferring flammable liquids unless they are specifically designed to dissipate static. Use anti-static mats, wrist straps, or grounding systems to safely discharge static electricity. Avoid using plastic containers or synthetic clothing that can generate static. Ensure proper ventilation to prevent the accumulation

of flammable vapors. Regularly inspect and maintain electrical equipment to prevent unintentional sparks. Store flammable materials in approved safety cabinets and handle them in fume hoods.

Real-world Example: The U.S. Chemical Safety and Hazard Investigation Board (CSB) has documented several incidents where electrostatic discharge was the root cause of fires or explosions in chemical plants and laboratories. These cases highlight the importance of understanding and mitigating static electricity risks.¹⁴

Extinguisher classification

In the laboratory, students will carry out several types of processes. In this context, it is important to understand that different types of fire extinguishers are available for use in the lab. These extinguishers are classified according to the type of fire they are designed to combat. Table 2 shows this classification.¹⁵

Table 2 Fire classification and proposed extinguishers.

Class of fire	Description	Type of extinguisher
A	Fires in ordinary combustible materials, such as wood, cloth, paper, rubber, and many plastics.	DCP Dry chemical powder. Monoammonium phosphate and/or potassium sulfate
B	Fires in flammable liquids, combustible liquids, petroleum greases, tars, oils, oil-based paints, solvents, lacquers, alcohols, and flammable gases.	CP Dry chemical powder. monoammonium phosphate and/or potassium sulfate.
C	Fires that involve energized electrical equipment.	Aqueous Film-Forming Foam (AFFF). Carbon dioxide (CO ₂). Dry chemical powder. Gases (such as halon, halocarbon). Deionized water
D	Fires in combustible metals, such as magnesium, titanium, zirconium, sodium, lithium, and potassium.	Sodium methoxide. Sodium chloride
K	Fires in cooking appliances that involve combustible cooking media (vegetable or animal oils and fats).	Potassium acetate. Aqueous Film-Forming Foam (AFFF)

Students must receive adequate training in the use of fire extinguishers. Some important instructions should be consulted in the corresponding manual or safety guidelines. Some important instructions must be consulted in the CCOHS web site.¹⁶ It is worth mentioning that a fight should never be fought if you do not know the material that is burning, what extinguisher is necessary, the fire is spreading. It is important to emphasize that proper training is essential. These types of courses are usually provided by institutions when you begin working.

Procedure for handling reagents:

In chemical processes, certain reactions involve reagents classified as highly hazardous. Typical examples include catalytic hydrogenations using palladium, the application of strong oxidizing agents, reactions involving organometallic compounds, and the manipulation of explosive substances. These operations demand strict adherence to specialized safety protocols. Additionally, it is essential to ensure proper inert blanketing of all materials prior to use to minimize the risk of uncontrolled reactions.

- Inerting the flask:** A specific case of inerting or blanketing occurs when preparing a reaction flask in the laboratory. Ambient air contains approximately 20% oxygen, which is also present inside the flask. Since oxygen is a key component for combustion, it

must be removed or displaced to prevent fire hazards. Combustion occurs when three elements coincide: oxygen, a fuel, and an ignition source commonly referred to as the fire triangle. Inerting (or blanketing) is the process of introducing an inert gas into a combustible mixture to reduce the oxygen concentration below the limiting oxygen concentration (LOC).¹⁷ Nitrogen is typically used as the inerting gas. The procedure consists of sweeping the flask with nitrogen to displace oxygen. At the industrial level, equipment is considered safe when residual oxygen reaches 4 to 5%. In laboratory operations, sweeping the flask with nitrogen for approximately five minutes is generally sufficient to achieve an adequate level of inerting.

- Palladium on charcoal hydrogenations:** These reactions employ palladium supported on activated charcoal as a catalyst. This material typically contains a small amount of water; however, due to its pyrophoric nature, it can ignite spontaneously upon exposure to air. Additionally, the process involves hydrogen gas, which is odorless and burns with an almost invisible flame, increasing the risk of undetected ignition.
- Key safety cautions include are, avoid spilling any quantity of catalyst. In case of a spill, clean the area immediately and collect residues in a sealed container, ensure the availability of

a hydrogen detector during hydrogenation operations. At the end of the reaction, release residual hydrogen slowly in a fume hood, ensuring that no ignition sources are present; after finishing the reaction, the catalyst has residual hydrogen, handling with care this residue. Recent reports provide detailed guidelines on laboratory hydrogenation setup and associated safety measures.¹⁸

d. Organometallic reagents: Organometallic compounds contain a metal atom within their molecular structure and are highly reactive. These reagents can react violently with air and water, often generating intense heat and, in many cases, causing ignition. For this reason, the use of completely dry materials is critical to prevent hazardous reactions. The setup for transferring these reagents typically using cannulas or syringes must be thoroughly inspected to ensure integrity and proper operation. Cooling systems should be adequate to dissipate the heat generated during the reaction. Additionally, a Class D fire extinguisher must be readily available, and a contingency plan should be implemented to address potential emergencies. Special attention must be given to these experiments, as they are among the most dangerous in laboratory practice. For detailed guidelines on safe handling, consult the referenced article on organometallic safety procedures.¹⁹

e. Cyanide reactions: The cyanide functional group is highly versatile in organic synthesis, as it can be transformed into various other functional groups. However, the primary hazard associated with cyanide reagents is their extreme toxicity, which can be fatal even at low exposure levels. For this type of reaction, strict safety measures are essential, including rigorous control of contamination and prevention of spills. Deactivation solutions must be readily available, such as dilute sodium hydroxide and sodium hypochlorite solutions, to neutralize cyanide residues effectively. Extreme caution must be exercised when handling cyanide compounds, and these reactions should only be performed by personnel with proven expertise. A contingency plan must be in place to address accidental exposure or spills. For detailed procedures, refer to the standard operating protocol for cyanide handling.²⁰

f. Acid and base reactions: Many acid or base reactions are highly exothermic and can generate significant heat. For example, sodium hydroxide releases considerable heat during dissolution and is both strongly basic and highly corrosive. Conversely, certain acids react violently with water, posing severe hazards. To prepare solutions safely, always add acid slowly to water never the reverse to minimize splashing and excessive heat generation. These operations can cause severe chemical burns if not handled properly. Appropriate personal protective equipment (PPE), such as face shields, gloves, and lab coats, is mandatory during these procedures.

g. Oxidizing agents: Certain oxidizing reagents react vigorously with water, even in trace amounts. Therefore, it is essential to ensure that all laboratory materials and equipment are completely dry before initiating the reaction. For example, phosphorus oxychloride can release a significant amount of energy during its reaction and becomes even more hazardous upon contact with water. Strict adherence to drying protocols and the use of appropriate personal protective equipment (PPE) are mandatory when handling these substances. An example of the use of phosphorus oxychloride has been recently published.²¹

h. Explosive materials: Certain compounds are highly sensitive to mechanical shock and can detonate upon sudden impact; these are

classified as *shock-sensitive compounds*. The detonation of such substances can result in catastrophic consequences, including severe damage and injury. Due to their instability, these reagents are subject to strict limitations in transportation and storage. For example, hydrobenzotriazole is shock-sensitive in its anhydrous form but significantly less hazardous in its hydrated form, which provides a safer alternative. Common examples of shock-sensitive compounds include organic azides, peroxides, and nitro derivatives. Handling these materials requires specialized protocols, such as minimizing physical disturbance, maintaining controlled temperature conditions, and ensuring the availability of appropriate protective equipment and blast shields. Some functional groups potentially explosives are: acetilenes, nitroso, nitrites, epoxides, N-metilderivatives, azo, diazo, nitro, nitrates, traizen, peroxides, among others.²²

i. Carbon monoxide: Carbon monoxide (CO) is an extremely hazardous gas: it is colorless, odorless, highly toxic, and flammable. In laboratory settings, CO is sometimes used for carbonylation reactions, which are among the most dangerous procedures due to the gas's properties and associated risks. To safely perform these reactions, it is essential to ensure that all laboratory equipment is completely leak-free. A carbon monoxide detector must be installed and operational at all times. Additionally, an efficient fume hood is required to capture and eliminate any residual gas. Personnel must be trained in emergency protocols for CO exposure, and appropriate personal protective equipment (PPE) must be worn throughout the process. (Figure 7)²³

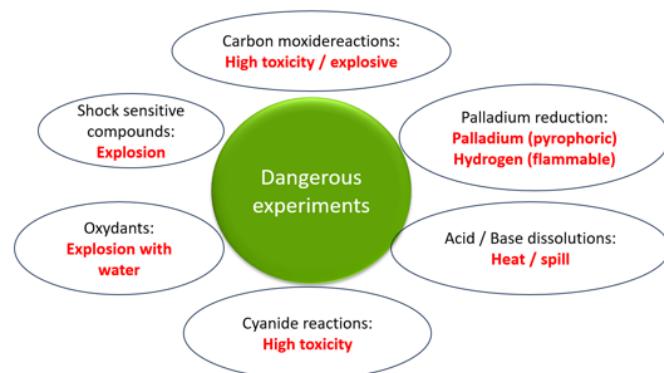


Figure 7 Some dangerous experiments on organic chemistry.

An excellent source of information on chemical properties can be found in Bretherick's Handbook of Reactive Chemical Hazards.²⁴

Deactivating reagents

All chemical reactions generate by-products or effluents. After completion, any remaining intermediates and excess reagents must be neutralized or eliminated safely. This section outlines common quenching practices. In general, the following conditions must be observed:

Slow addition of the quenching agent

Control of heat generation during the process

Cooling of the reaction vessel prior to and during quenching

a. Aluminum Borohydride: Quenching aluminum borohydride produces boronic esters, which are typically hydrolyzed using dilute hydrochloric acid. This process is highly exothermic and requires strict temperature control and slow reagent addition to prevent hazardous conditions.

- b. Hexyllithium: Quenching hexyllithium must be performed using a dilute acidic medium, such as acetic acid. This process is highly exothermic; therefore, strict control of the quenching solution is essential. The acid should be added very slowly to the reaction mixture to manage the heat generated and prevent hazardous conditions. Adequate cooling of the reaction vessel and continuous temperature monitoring are mandatory throughout the procedure. Personnel must wear appropriate PPE and follow established safety protocols for handling pyrophoric and highly reactive organolithium compounds.
- c. Cyanide: Reactions involving cyanide compounds are extremely hazardous due to their high toxicity. Any spill must be treated immediately with a deactivation solution consisting of sodium hydroxide combined with sodium hypochlorite. This neutralization process is highly critical and must be carried out under the direct supervision of an experienced professional. Personnel must wear full PPE, including chemical-resistant gloves, face shields, and lab coats, and ensure proper ventilation during the procedure. Emergency protocols for cyanide exposure should be readily available and strictly followed.
- d. Sodium hydroxide: Reactions involving sodium hydroxide are typically quenched using hydrochloric acid until the solution reaches a pH of approximately 7. The exact amount of acid required depends on the nature and scale of the reaction. This process is exothermic; therefore, slow addition and continuous temperature monitoring are essential to prevent hazardous conditions.
- e. Hydrochloric acid: Conversely, reactions involving hydrochloric acid must be quenched with a basic solution, such as sodium bicarbonate, sodium hydroxide, or another suitable base. The neutralization should be performed gradually to control heat generation and avoid splashing. Proper PPE and ventilation are mandatory during these operations.
- f. Acyl chlorides: Reactions involving acyl chlorides generate chloride ions as by-products. To neutralize these, a scavenger is typically employed to trap the chloride ion. Common scavengers include triethylamine or similar organic bases. The addition of the scavenger must be controlled to avoid excessive heat generation and ensure complete neutralization.
- g. Palladium on charcoal: Palladium supported on charcoal poses a significant fire hazard when dry, as palladium is pyrophoric. A standard procedure involves filtering the catalyst through a Celite pad and removing all palladium dust. The residue must remain wet at all times to prevent spontaneous ignition. Proper disposal protocols and continuous monitoring are mandatory during this process.

Contingency plan

A very important part of the life at the laboratory is to be prepared for the most common causes of problems, because it is necessary to ensure the safety of the student and people. In addition, the community must be taken in account. The main problems that could occur are the following scenarios.

- a. Chemical spill: Could generate toxic exposition, fire, chemical burns, contamination. It is necessary to have containment materials, and spill kits (zeolite). As an emergency response it will be necessary Evacuate area, first aid to affected students, wear safety equipment, use spill kit, and communicate to the responsible, call medical emergency.

- b. Fire /explosion: In the event of an explosion, it may be necessary to manage chemical burns, injuries, property loss, and contamination. As preventive measures, fire extinguishers and fire brigades should be available. Additionally, if possible, use a fire extinguisher, activate the alarm, provide first aid to affected individuals, wear appropriate safety equipment, use a spill kit, and notify the responsible personnel. Contact the fire department and the medical emergency services immediately.
- c. Gas leak: In the event of a gas leak, there is a risk of asphyxiation, explosion, injury, or death. As a preventive measure, the use of gas detectors is critical. If a leak occurs, it is necessary to evacuate the premises immediately and notify the responsible personnel and the fire department.

The contingency plan must be customized following the inherent risk of the facilities.

The importance of communicating risk in the laboratory

History and personal experience clearly show that protecting students and young professionals in the laboratory begins with education and communication. One of the most effective ways to ensure safety is to clearly explain the risks and hazards associated with each experiment. For example, in the personal experience of one of the authors (26 years of experience), when it was beginning work with hydrogenation reactions, no one explained that palladium is pyrophoric meaning it can ignite spontaneously in air and that hydrogen burns with a nearly invisible flame, making it especially dangerous. Without this knowledge, the risk of fire or explosion was significantly underestimated. Over time, as experience grows and more complex equipment is used, it becomes clear that some critical safety information is not always well communicated.

This gap in communication can lead to preventable accidents. Why risk communication matters, well because new students and professionals often lack the experience to recognize subtle or hidden hazards. Assumptions that “everyone knows” certain risks can lead to dangerous oversights. Open dialogue about risks fosters a culture of safety and shared responsibility. Always explain the specific hazards of each experiment, especially when working with reactive or hazardous materials. Encourage questions and create a safe space for students to express uncertainty. Document and share lessons learned from past incidents or near misses. Mentor new students and new professionals by sharing real-life experiences and safety tips.

Near-miss reports:a key to preventing future accidents

A near miss is a minor incident or unsafe condition that could have led to an accident but did not this time. These events are early warning signs of potential hazards and should never be ignored. In fact, a pattern of near misses is often a symptom of a deeper safety issue. Why Near-Miss Reporting Matters. Unreported near misses can lead to repeated unsafe conditions, increasing the likelihood of a serious accident. Reporting near misses helps identify risks early, allowing corrective actions before harm occurs. It promotes a proactive safety culture, where everyone contributes to preventing incidents. Common Near Misses in Laboratories. Minor chemical spills that are quickly cleaned up without injury. Small fires that extinguish on their own or are easily controlled.

Equipment malfunctions or failures that do not cause harm but indicate potential danger. Report the near-miss incidents helps to encourage open communication. Create a non-punitive environment

where students and staff feel safe reporting incidents. Document all near misses helps maintain updated the records. And it could be possible analyze trends and in consequence implement corrective actions and preventive actions. Finally, the lesson learned can be shared with the team to avoid recurrence. An interesting article about this topic has been published recently.²⁵

Post-experiment: managing laboratory waste responsibly

While much attention is given to preparing for laboratory experiments, it is equally important to consider what happens after the experiment is completed. Every laboratory activity generates residues and waste, which must be handled with care to protect both people and the environment.²⁶

Types of laboratory waste: After an experiment, various types of waste may be produced, including Used solvents, empty reagent containers (bottles, cans, bags), quenching solutions, used catalysts, aqueous waste phases and generated gases or vapors. Each of these waste types may pose different hazards and must be classified and managed appropriately.

Proper waste management practices: Waste must be classified based on its chemical nature (e.g., flammable, corrosive, toxic, reactive). Laboratories typically have a designated waste storage area where residues are collected and separated. Waste must be handed over to a licensed hazardous waste management provider, who is responsible for proper treatment and disposal. Disposal must be tracked through a waste manifest, which records the type, quantity, and destination of each waste stream. Other typical issue is the volume of waste generated and normally depends on; the number and scale of experiments conducted, the types of chemicals used and the efficiency of the procedures, including solvent recovery and minimization strategies. Proper waste management is not only a regulatory requirement but also a key component of sustainable and responsible laboratory practice. It ensures environmental protection, reduces health risks, and promotes a culture of accountability in scientific work. Finally, it is worth mentioning that the book *Prudent Practices in the Laboratory* is an excellent compendium of several topics discussed in this article.^{27,28}

Conclusion

Laboratory experience is one of the most powerful ways to learn science. However, this hands on learning must always be accompanied by a strong commitment to safety. One of the most effective ways for students to stay safe is by taking personal responsibility for their own protection and actions. Wearing the appropriate personal protective equipment (PPE) is essential. Equally important is having a clear understanding of the experiment to be performed this allows students to anticipate the materials, equipment, and safety measures required. A clean and organized workspace further reduces the risk of accidents and supports accurate, reproducible results. Additionally, never working alone in the lab ensures that help is available in case of an emergency.

Other important topics to know are, read the safety data sheets and verify that the equipment is correct. To support these practices, this article proposes a non-exhaustive checklist that students can follow before and during laboratory work. This checklist is intended as a foundational tool that students can adapt and improve over time as they gain more experience and knowledge, knowing the contingency plan including emergency exits, first aid procedures, and the location of safety equipment is crucial for responding effectively to unexpected

situations. Finally, all this basic knowledge will help the student to develop a self-conscious about safety. The next phrase summarizes this work. A Culture of Safety Begins with Awareness and Action.

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Conflicts of interest

The authors declare that there are no conflict of interest.

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